Newer Modifications in IOL Technology

Amit Porwal, MBBS, DO, FASCS, FLDR, FAEH., **Abhishek Patel,** MBBS, MS., **Kavita Porwal,*** MBBS, MS, DNB(Ophth)
Choithram Netralaya, Indore, India, *Consultant Paediatric Ophthalmology & Strabismus, CHL Hospital, Eyesite Clinic, Indore

Abstract:

IOL technology is one of the fastest developing technologies in recent years in ophthalmology. Monofocal in the bag IOL is the most commonly used IOL all around the world. In developing countries, use of this IOL is almost standard. There are many different IOL options in the market and appropriate IOL must be individualized for each patient to reach perfect postoperative outcomes. Presbyopia correcting intra ocular lenses (IOLs) have revolutionized refractive cataract surgery, as there is continuous evolution in materials and optical designs going on which allowed ophthalmologist for a better balance of functionality of IOL while reducing unwanted symptoms. Presbyopia correcting IOLs have become a focus of attention in IOL selection discussions with patients due to the increasing number of activities that require near and intermediate vision in our modern world, such as smart phones, and computers. Numerous IOL platforms have been designed to extend the range of focus as "presbyopia correcting IOL" options, and three main categories can be identified: those including multifocality (functional bifocal and trifocal IOLs), accommodative or pseudo accommodative IOLs, and extended depth of focus (EDOF) IOLs. Regardless of the optical design or strategy chosen to achieve relative spectacle independence, a certain degree of visual compromise can still be anticipated. In this article, we have tried to enumerate all the recent developments in IOL technology, their specific mechanisms, characteristics and performances to help ophthalmologists to decide the best possible Intra ocular lens for his/her patient, to achieve the best possible visual outcome and to his patient's satisfaction.

Introduction:

IOL technology is one of the fastest developing technologies in recent years in ophthalmology. Monofocal in the bag IOL is the most commonly used IOL all around the world. In developing countries, use of this IOL is almost standard. There are many different IOL options inthe market and appropriate IOL must be individualized for each patient to reach perfect postoperative outcomes.

History:

In 1949, English ophthalmologist Dr. Harold Ridley performed first successful intraocular lens (IOL) implantation. He presented this new surgical method in 1951 Meeting of American Academy of Ophthalmology (AAO) and reported results of first 8 operations in 1952.[1] In those days, many of ophthalmologists opposed to this method because many complications were seen such as unpredictable high postoperative refractive error, uveitis, glaucoma, corneal decompensation and permanent visual loss. Nevertheless Dr Ridley continued and kept on developing newer methods for cataract extraction and IOL implantation.

Original Ridley lens was designed for use in posterior chamber. Subsequent designed IOLs were implanted in anterior chamber because there were no modern operation microscopes in those days. So along with operating instrument modification and development for microsurgery there was constant development in IOL shape, design, material etc. Finally, modern IOLs were designed for use in anatomical localization of human crystalline lens.

Changes in IOL modification is based on

- Advances in IOL materials
- Advances in IOL shapes and designs.

Material:

If we talk about materials, PMMA (polymethyl methacrylate) have ruled as best material for IOL since original Ridley lens was used. As time passes IOLs have divided in two main category's non foldable and foldable IOLs. Non foldable IOLs are made of PMMA and foldable IOLs are made of silicon and acrylic.

Acrylic IOLs

Acrylic bio material is the most commonly used optic material. Now these acrylic lenses were further divide on their bases of their behaviour inside ocular environment in two types

1. Hydrophilic acrylic lenses and

2. Hydrophobic acrylic lenses.

Hydrophilic, as the name suggests, absorbs and retains water. It is the consistency in the ability of the material to take up and retain the water, which make refractive power and elasticity deviations in intra ocular lens. While in hydrophobic lens, the material tends to absorbs minimal amount of water. The Refractive power of Hydrophobic lens is depends on the molecular orientation and not on molecules itself. It is for this reason, the reproducibility, accuracy, and sensitivity of the refractive outcome will be high in case of hydrophobic IOLs.

Selection between hydrophilic and hydrophobic IOL depend upon capsular bio compatibility. Capsular bio compatibility of hydrophilic acrylic IOL is low. Capsular bio compatibility is very important because it affects long term visual outcomes negatively through posterior capsular opacification (PCO) and deformation of IOL surface.[2] For this reason, most of the cataract surgeons use more common hydrophobic acrylic IOL than hydrophilic acrylic IOL if possible. Uveal bio compatibility and some optical properties of hydrophilic acrylic IOL are high.[3,4] Additionally, one study reported bacterial adhesion to surface of IOL is fewer in hydrophilic acrylic IOL than other IOLs.[5] New designed hybrid acrylic IOL combine advantages of two acrylic IOLs and provides higher uveal and capsular bio compatibility. Thus, this material yields better surgical outcomes via reducing postoperative anterior chamber cells and PCO rate.[6]

Heparin coating is a surface modification that enhances the uveal bio compatibility of IOL. Fewer aqueous flare are seen after implantation of heparin coated IOL.[7] Although heparin coated IOL increases the risk of PCO, but this increase in PCO is not found statistically significant.[8] And this IOL can be used in patients with high-risk for postoperative intraocular inflammations.

Silicon IOL

Polymers of silicone and oxygen have been employed as IOL material since 1984, with the purpose of implanting the IOL through an incision narrower than IOL diameter. The refractive index is usually between 1.41 and 1.46, the optic diameter is 5.5–6.5 mm. Current models are 3 piece, with PMMA, polyvinyl difluoride (PVDF) or polyamide haptic. Because of the low refractive index, the optics is rather thick, requiring incisions larger than 3.2 mm to implant higher power lenses. However, the abrupt opening of silicone IOLs inside the anterior chamber remains a problem for surgeons.

Designs and Shapes:

The variation in optic and total diameter of IOL is limited. Larger optical size is advantageous in visualisation of peripheral retina, it is disadvantageous in terms of folding and implantation through small incision. Optic diameter of IOLs is almost standard due to this limitation. When total diameters are compared, average rotation and stabilization are similar in IOLs with 12 mm and 13 mm total diameters.[9]

There are various haptic designs on the market such as plate haptic, C haptic, modified C haptic, J haptic, quad ripod haptic and more. A study comparing various haptic types reported that double C haptic contacts the lens capsule at 4 points. Double C haptic design maintains anteroposterior and rotational stability of IOL. [10] In postoperative 3rd month, the average rotation of IOL was found as 1.85 degrees in this haptic design .[11]

Planar and angular haptics are another differentiation in haptic design. There can be 5, 10 or more degrees in optic haptic junction of IOL with angular haptic. IOL deformation is less in planar haptics while anterior capsule opacification is less in angular haptics.[12] PCO and IOL decentralization occur equally in both of planar and angular haptics.[13]

With advancement in optic design, toric IOL are in high demand for correction of astigmatism, toric IOL can correct very high degree astigmatism such as 30 dioptres but cylindrical power of toric IOL on the market are limited. High degree cylindrical power causes rotational instability and increased postoperative refractive error after cataract surgery because cylindrical power help in rotational stability of an intraocular lens. This reason, postoperative refractive predictability of surgery reduces after implantation of high degree toric IOL.[14,15]

All IOLs in the market block UV electromagnetic radiations. Additionally, some IOLs contain blue and yellow filters to protect retina from photo toxicity. Thus, the light permeability of IOL is approximated to the young human natural lens. But one study shows that blue light is necessary for scotopic vision in night and melatonin suppression in day.[16] So, benefits of these filters are controversial and further research is needed. At least, we know that colour filter coated lenses do not negatively effects postoperative visual acuity and contrast sensitivity.[17]

Refractive power of IOL is same in all over the surface of IOL in spherical optical design while, in aspheric, optic makes overrefraction in periphery of IOL and causes decreases spherical and chromatic aberrations, which is not in case of Spherical optical design, where there is an increase in spherical and chromatic aberration which reduce visual acuity and contrast sensitivity.[18] Additionally, photic phenomena such as glare and halo occur more commonly in spherical optic than aspheric optic.[19] For these reasons, IOL with aspherical optical design is used more frequently than IOL with spherical optical design.

Recent modification in Intraocular lenses

There is constant evolve in technology behind intra ocular lenses in recent years

- Aspheric IOLs, monofocal IOLs that compensate for spherical aberration;
- Toric IOLs, designed for eyes with astigmatism; and
- Presbyopia-correcting IOLs, including accommodating and multifocal lenses.

Aspheric IOLs

An aspheric IOL aligns the light rays to compensate for the positive corneal aberration, resulting in enhanced clarity and image quality. In addition, the use of thinner IOLs permits surgeons to create smaller incisions, which are more likely to be self-sealing.

Currently available aspheric IOLs manufactured by Alcon, Abbott Medical Optics (AMO), Bausch & Lomb, Hoya, Lenstec, and STAAR. Studies comparing the use of an aspheric lens with a traditional lens found that although visual outcomes were the same, eyes receiving the aspheric lens demonstrated superior functional performance in contrast sensitivity with a night-driving simulator and improvement in contrast sensitivity.[20,21]

Multifocal IOLs

These Intraocular lens are design to give us near, intermediate and far vision with single IOL, Multifocal IOLs have two distinct foci with blurry vision in between. Focusing on one, may cause glare and haloes from the other. These are the main drawbacks cause's disturbances which are especially noticeable under dim lighting conditions. However, 2 studies demonstrated good patient satisfaction and visual outcomes with the multifocal lenses .[22, 23]

Bifocal IOLs

Mplus, Mplus X (Oculentis) and SBL-3 (Lenstec) aresingle-piece refractive multifocal IOL of hydrophilic acrylic with a hydrophobic surface. It has an inferior surface–embedded segment with a near addition (add) of+3.00 D. It is based on rotationally asymmetric segmented bifocal IOLs with sector-shaped near vision segment giving two focus zones for better depth of focus (Figure: 1 & Figure: 2).

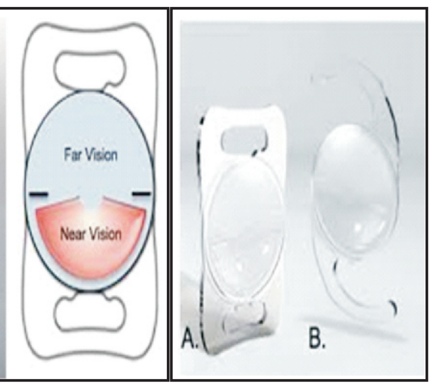

Figure 1: SBL-3: Segmented Bifocal Lens Source: https://www.lenstec.com/

Figure 2: Distance and near sectors of the aspheric nonrotational symmetric multifocal IOL. A: Plate-haptic model. B: Model with Cloop haptic.

Source: Jan A. Venter, MD, J Cataract Refract Surg 2013.

Trifocal IOLs

FineVision (PhysIOL), PanOptix (Alcon)(Figure: 3), AT Lisa (Zeiss)(Figure: 4) and AcrivaReviol (VSY Biotech) are trifocals (3 points of focus, near, intermediate and far). These trifocal lenses are also available on toric platform which help in managing astigmatism. Trifocal lens help in providing clear and better intermediate vision compared to bifocal intraocular lens by using second-order light diffraction and asymmetric light distribution.

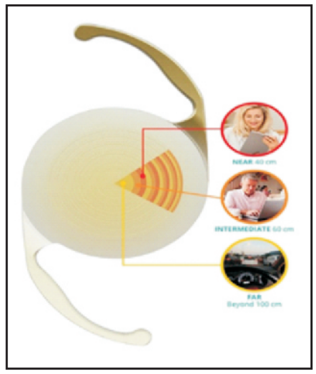

Figure 3: Acry Sof Pan Optix IOL

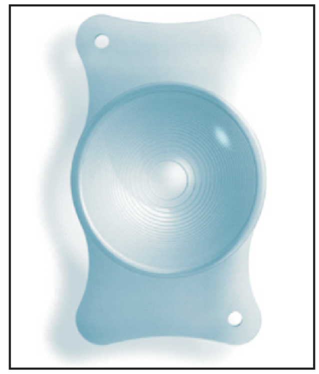

Figure 4 : AT LISA tri 839 MP.

Source: Wolfgang Riha, MD

Source: https://www.eyeassociatesoftallahassee.com

EDOF IOLs (Extended depth of focus)

The basic principle behind EDOF IOLs is to create a single elongated focal point to enhance the depth of focus or range of vision.[24] EDOF IOLs is based on diffractive echelette designand forms a step structure. The height, spacing, and profile of the echelettes are optimized to achieve constructive interference of light from different lens zones, thus producing a novel light diffraction pattern. In addition, proprietary achromatic technology and negative spherical aberration correction improve the image quality.[25]

EDOF IOLs have generally given good uncorrected distance and intermediate vision: however, near vision from standard multifocal may be better. Therefore, it may be implanted in the dominant eye first followed by a micromonovision strategy with EDOF IOL or a multifocal in the non-dominant eye is recommend by many leading ophthalmologist.

EDOFs like the Tecnis Symfony IOL (AMO) (Figure: 5)use a biconvex design, anterior aspheric surface, posterior achromatic diffractive surface with an echelette design to give better intermediate vision with less haloes and light scatter.We have a latest IOL from Tecnis family called Tecnis synergy IOL. The Tecnis Synergy IOL provides a broad range of continuous vision covering from distance to 33 cm; eliminates the visual gaps present in trifocal and other multifocal technology, offering patients the freedom to focus within the range; continues to deliver superior performance in low-light conditions; and demonstrates reduction in halo intensity for tasks like night driving, as demonstrated in clinical simulations.

Tecnis Eyhance IOL is designed to extend depth of focus from distance to intermediate vision. In this, there is a continuous change in power from the periphery to the center of the lens, creating a unique anterior surface that improves intermediate vision, maintains distance image quality comparable to aspheric monofocal IOLs, delivers a profile of photic phenomena similar to monofocal and keeps on reducing spherical aberration to near zero. Tecnis Eyhance IOL, unlike other monofocal lenses, is not based on a spherical-aberration (SA) based or zonal design, but the continuous power profile is created with a higher order asphere.

AT LARA 829MP (Zeiss) (Figure: 6) is the latest EDOF lens to appear. It has a diffractive aspheric design, chromatic correction and smoother phase zones that optimise contrast sensitivity and minimise light scattering and visual side-effects.

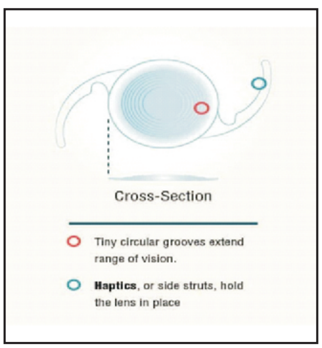

Figure 5 :
Tecnis Symfony IOL
Zeiss AT LARA toric
Source:
https://www.zeiss.com/

Figure 6 :
Zeiss AT LARA 829MP & 929M/MP
Source:
https://alexandria.vancethompsonvision.com

Small-aperture IOLs also extend depth of focus. These are especially effective in post LASIK, post RK eyes and in irregular corneal astigmatism. In the presbyopia eye, the natural lens cannot compensate for defocused peripheral light that degrades image quality and range of vision while The IC-8 IOL uses small aperture technology disrupting peripheral light rays and allowing central focused light to reach the retina resulting in clear vision across a broad range of distances.

IC-8 IOL combines the principle of small Aperture optics with a high quality aspheric mono focal. IC-8 is one-piece hydrophobic acrylic IOL. IC-8 IOL can compensate for up to 1.50 D of astigmatism without needing to be placed on a particular axis, just like pin hole principle. The small (1.36 mm) non-diffractive aperture of the IC-8 lens, together with the absence of diffractive surface structures in the IOL, allows it to act as a 'universal' corrective lens (Figure: 7).

XtraFocus Pinhole implant (Morcher) designed by Trinidade et al. is another small-aperture sulcus IOL made of black acrylic with a central pinhole(Figure: 8). Fundus imaging is possible and vitreo-retinal surgery can be performed when required through both these IOLs, IC-8 and XtraFocus Pinhole implant.

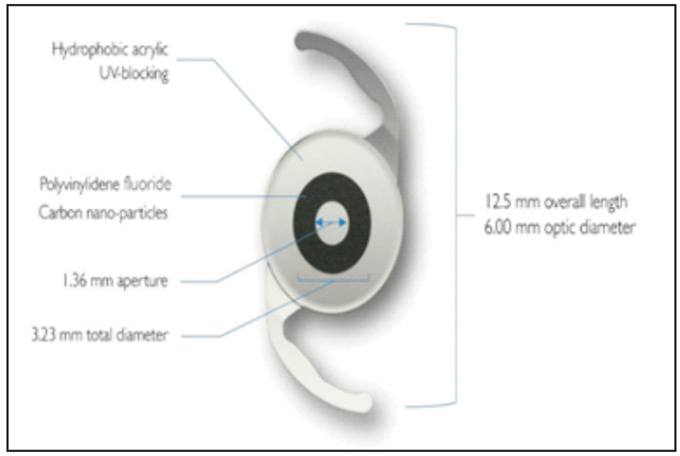

Figure 7 : IC-8 Small aperture IOL
(Lens platform to deliver the first implantable small aperture intraocular lens.)
Source: https://theophthalmologist.com/

Figure 8 :
Xtra Focus Pinhole implant
Source: https://eyetube.net/

ACCOMMODATIVE IOLs

Accommodating IOLs are designed to mimic the changes in the natural lens by inducing a transient and rapidly reversible change in the optical power of the eye

These changes can be done by two ways

1. Change in shape of IOL
2. Change in Position of IOL within bag.

Accommodative IOL help to provide good vision for near, intermediate and far. Accommodating IOLs generally are not associated with loss of contrast sensitivity, but accurate placement is essential for optimal results. There are some partial accommodating IOLs which rely on changes in axial position of the IOL like Single-optic IOLs such as Crystalens

(B&L), 1CU IOL (HumanOptics), Tetraflex (Lenstec) (Figure:10) as well as dual-optic IOLs such as Synchrony (AMO) give antero-posterior movement said to give some degree of both near and distant vision

Synchrony IOL (Visiogen, Abbott Medical Optics, AMO, and Santa Ana, Calif.) is a single-piece dual-optic, silicone lens designed to mimic the natural lens (Figure: 9). It has a 5.5 mm high plus anterior optic of +32 D, coupled to a 6.0 mm negatively powered posterior optic. The concept is that these two lenses are separated by a spring-activated mechanism. The haptic separate the lenses at a given distance under constriction of the capsule, and during relaxation of the capsule following accommodative effort, anterior movement of the positive anterior optic produces increased power for near tasks.[26]

Several options now available are getting closer to the goal of restoring accommodative vision. Some of these act by various mechanisms, including changing optic shape, curvature or thickness to change focus, In-the-bag accommodative IOLs are an interesting innovation.

Figure 9 :
Synchrony dual-optic lens
Source: Abbott Medical Optics

Figure 10:
Tetraflexlens
Source:
Paul. J. Dougherty. M.D

FluidVision (PowerVision) IOL

FluidVision IOL is a hydrophobic acrylic lens with a hollow optic and two hollow haptic that are filled with a refractive index-matched silicone fluid and are connected by fluid-filled channels (Figure: 11).

When the ciliary muscle contracts in response to a near stimulus, the resulting relaxation of zonular fibres causes the capsular bag to contract, forcing fluid from the haptic into the optic, making it more convex and thereby increasing its dioptric power.

"FluidVision movement translates into a true shape change for seamless vision from near to distance," said Dr Nichamin, Vail, Colorado, USA. The FluidVision 20/20 (PowerVision) can provide a broader range of focus than earlier models, according to the results of a study presented by Louis D. "Skip" Nichamin, MD at the 36th Congress of the ESCRS in Vienna, Austria. And in this study Dr Nichamin predict the ability to meet design objectives and deliver 20/20 vision at all distances .[27]

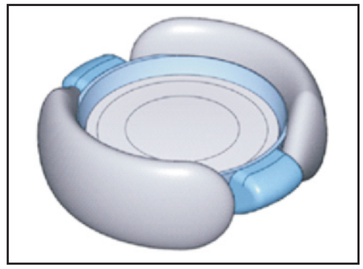

Figure 11 :
Fluid Vision IOL
Source: Power Vision

Sapphire IOL (Elenza)

ELENZA combineselectronically controlled, remotely programmable, customisable nanotechnology, artificial intelligence (neural networks-based memory), and advanced electronics to seamlessly autofocus an optic from far to near without movement focus in response to pupillary changes. Therefore, the lens doesn't have to rely on precise contact with ciliary muscles to move and accommodate properly.

Juvene (LensGen) is a two-lens modular IOL made of a monofocal base lens into which a fluid-optic accommodating component that changes curvature is placed.

WIOL-CF IOL

WIOL-CF accommodative IOL (Figure: 13) was invented by Professor Otto Wichterle and his collaborators at the Institute of Macromolecular Chemistry in Prague. Its design is based on the biomimetic principle: the hydro gel material used and the lens geometry simulate some of the key properties of the crystalline lens itself.The shape of the lens may be biconvex, planoconvex or convex–concave, according to the dioptric power. The suggested A-constant for implantation is 120 and the recommended formula for the calculation of the dioptric power of the WIOL-CF is SRK II or SRK–T. Pseudo accommodation up to 2.5 dioptres can be achieved with the WIOL-CF. Its soft material and continuous contact with the posterior capsule allows some axial movement and deformation of the lens following ciliary muscle contraction.[28]

Possible Mechanisms of pseudo accommodation is the anterior–posterior movement of the implant due to tightening and relaxation of the ciliary muscle. This type of accommodation is similar to natural accommodation, but rather than occurring due to a change in lens curvature and refractive power, the movement of the lens causes an increase or decrease in the distance between the lens plane and the retina.

Dyna curve IOL (NuLens)

NuLensDynacurve IOL (Figure: 12) uses the capsular bag as a component of a moving diaphragm, consisting of the collapsed capsular bag, zonules, and the ciliary processes. The dynamic diaphragm transfers force from the contracting and relaxing of the ciliary muscles to the device attached to it. A piston, activated by the capsular diaphragm, pressurizes a small, rigid chamber containing a silicone gel. The chamber is fixated to the eye wall at the ciliary sulcus so that movements along the optical axis are avoided. The silicone gel is pressurized by forward movements of the capsular diaphragm and depressurized by backward movements of the diaphragm. The pressurized gel was displaced through a round hole in the anterior (or posterior) chamber wall to form a lens-shaped bulge that continuously changed its curvature in correlation with the ciliary muscle's movements. In the more current design, the "hole" has been replaced by a flexible membrane that can be modified to provide a spherical or aspherical dynamic surface. The prototype of the Dynacurve used in the pilot study required a 10- to 11-mm incision for implantation. To decrease the incision size and improve the surgical procedure, NuLens redesigned the Dynacurve IOL to what it looks like today—a base plate and a haptic unit that requires a 5-mm incision. With recent modifications to the rigid components of the lens, it is reasonable to expect a sub–3.5-mm incision version of the device .[29]

Figure 12 :
NuLensaccommodating IOL
Source: I. Howard Fine, M.D.

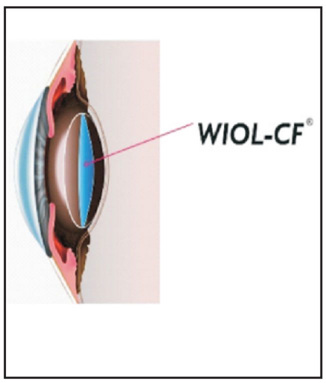

Figure 13 :
WIOL-CF
Source: behance.net

Special IOLs

Adjustable IOL

RxSight (formerly Calhoun Vision) developed the first light adjustable lens (RxLAL). The 3-piece RxLAL includes diffusible, photosensitive silicone macromers that are dispersed in the overall silicone matrix. Cataract surgery with RxLAL implantation is performed using standard techniques. Approximately 3 weeks later, the patient is refracted and a slit lamp based digital light delivery device (LDD) system is used to deliver the ultraviolet(UV) light in a precisely programmed pattern to induce a predictable change in the shape and refractive power of the optic. Treatment times rangebetween 60-120 seconds. After the newly adjusted refraction is confirmedseveral days later, a "lock-in" dose is given with the LDD to polymerizeall remaining macromer, at which point no further refractive change willoccur. Patients wear special UV blocking spectacles until the lock-in step iscompleted, after which they are no longer required. It is still under development.[30]

Perfect Lens LLC is developing a novel technology called refractive index shaping (RIS) that can modify the refractive properties of an implantedIOL in situ with a femtosecond laser.

Piggyback IOL

Piggyback lenses are best used when there is a refractive error which is large enough to correct with excimer laser treatment or IOL removal surgery.Piggyback IOL, which works best in patients with a hyperopic postoperative refractive error.[31]

For placement of piggyback lens in the capsular bag, an IOL with a negative shape factor such as the three-piece hydrophobic acrylic IOL is an excellent choice because at +30.00 D, all but 1/5th of the lens power is located on the posterior surface. For the ciliary sulcus lens, a large diameter, low profile, round edge, biconvex newer generation silicone IOL, such as the Staar AQ-2010V (+5.00 D to +30.0 D) or the extended power range Staar AQ-5010V (-4.00 D to +4.00 D) is recommended.

The Sulcoflex (Figure: 15) is a one-piece hydrophilic acrylic IOL with a 6.5-mm optic and 13.5-mm overall length. The optic has a round edge with a concave posterior surface and convex anterior surface. The haptic have 10° posterior angulation. These characteristics ensure separation of the IOL from the iris anteriorly, and the primary IOL posteriorly, resulting in significant reduction in the risks of ILO and iris chafing.

Anti Dysphotopic IOL

Dysphotopsia may be one of the most under recognized complications following otherwise unremarkable cataract surgery. Based on subjective symptoms, up to 20% of patents have negative dysphotopsia (ND), a temporal dark shadow after intraocular lens implantation. Other patients have positive dysphotopsia (PD), characterized by light streaks, arcs, central light flashing or star bursts. Some patients may have both ND and PD.[32]

Dr. Masket published reverse optic capture (ROC), either as a therapeutic or prophylactic measure for ND, in 2011. But primary ROC is not without concern. All of the eyes that underwent primary ROC placement had fibrotic PCO that required laser posterior capsulotomy within three months of the initial surgery. And long-term piggyback or sulcus placement have the potential for iris chaffing and decentration.

Dr. Masket has developed Anti Dysphotopsia IOL(Figure: 14) to avoid ND and PD, they are currently marketed in name of the Tassignon "BIL" (Morcher) and the Femtis (Occulentis).

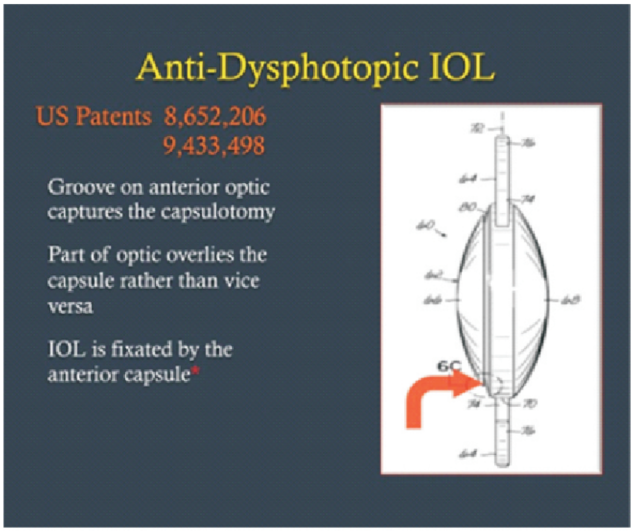

Figure 14: Anti-Dysphotopic IOLSulcoflex IOL
Source: Howard Larkin

Figure 15:
Source:
Richard S. Hoffman M.D

Age related Macular Degeneration (AMD) IOL

In 2015, a novel approach designed by Scharioth was introduced to the market: an intraocular lens (IOL), which can be placed into the ciliary sulcus as a secondary or add-on lens. Therefore, it offers a solution for pseudophakic AMD patients, as it is possible to be implanted any time after the cataract surgery. Moreover, only a small, corneal incision (approximately 2.4 mm in diameter) is required. The Scharioth macula lens for AMD has central 1.5mm diameter with +10D add giving magnification of about 2X.[33]

- The SML (Figure: 16) is made of a copolymer of Hydrophilic and Hydrophobic Acrylic with 25% water content.
- It comes with a UV absorber and is available with an additional blue light filter.
- The special convex-concave optic maintains distance between the implants, preventing IOLs from touching each other.
- Due to its round polished edges the IOL has no chafing effect.

Mode of action is using the near triad reflex of miosis accommodation and convergence.

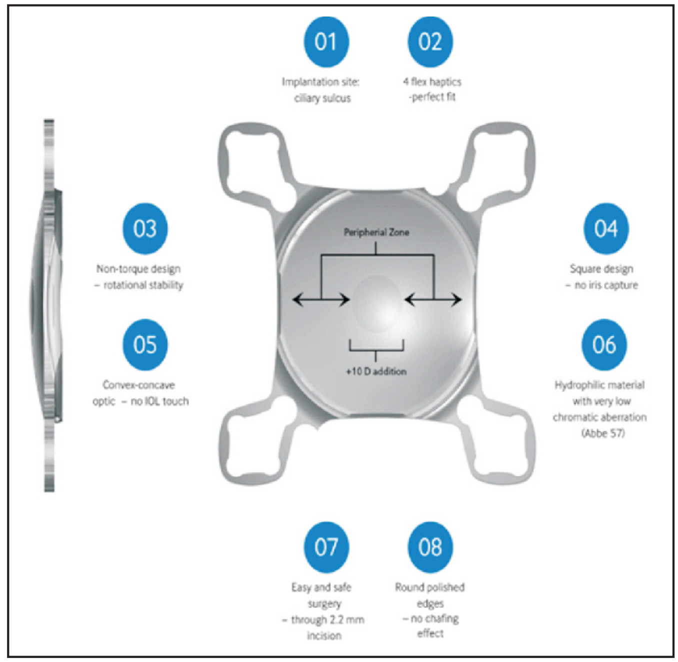

Figure 16: SML (Scharioth Macula Lens)
Source: Medicontur

Mini Well IOL

The Mini Well Ready IOL uses wavefront technology to enhance range of vision and compensate for presbyopia in cataract surgery and refractive lens exchange.The SIFI Mini WELL Ready (Figure: 17) is a preloaded, single-piece hydrophilic acrylic IOL with a hydrophobic surface. The overall diameter is 10.75mm with four closed-loop haptics with 5-degree angulation. The biconvex optic of 6mm diameter has three annuli, an outer monofocal zone and two inner zones with spherical aberrations of opposite signs. The innermost zone, or D1, is 1.8mm wide and has a positive spherical aberration, creating the intermediate focus. The middle zone, or D2, is 3.0mm wide and has a negative spherical aberration, contributing to near focus. The outermost zone, or D3, is a monofocal optic with a diameter of 6.0mm that is responsible for creating the far focus. The lens features an equivalent addition of +3.0D corresponding to a spectacle plane addition of +2.4D. Power ranges from 0 to +30D (0.5D increments from +10.5 to 30.0D). The company's estimated A-constant is 118.6.[34]

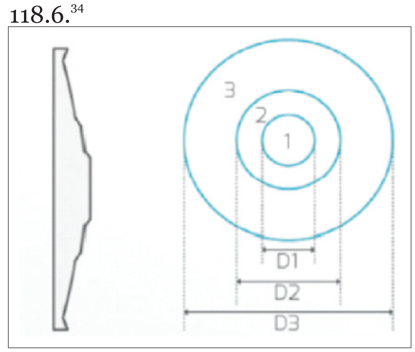

Figure 17:
MINI WELL Ready IOL
(The progressive optic has a central distance zone (1), a surrounding distance zone (2) with spherical aberration of the opposite sign, and a peripheral distance zone (3) with monofocal characteristics)
Courtesy of Sifi Medtech

References:

1. Ridley H. Intra-ocular acrylic lenses after cataract extraction. 1952. Bull World Health Organ. 2003; 81(10): 758-61. Epub 2003 Nov 25.
2. Avetisov SE, Gamidov AA, Novikov IA, Fedorov AA, Kas'yanov AA. Chemical microanalysis of mineral deposits on explanted hydrophilic acrylic intraocular lenses. Vestn Oftalmol. 2015 Jul-Aug; 131(4): 74-8.
3. Vinas M, Dorronsoro C, Garzón N, Poyales F, Marcos S. In vivo subjective and objective longitudinal chromatic aberration after bilateral implantation of the same design of hydrophobic and hydrophilic intraocular lenses. J Cataract Refract Surg. 2015 Oct; 41(10): 2115-24. [DOI: 10.1016/j.jcrs.2015.11.009]
4. Tang Y, Song H, Chen J, Tang X. Comparison of pseudophakic retinal straylight in spherical/aspherical and hydrophobic/hydrophilic intraocular lens. Int J Ophthalmol. 2015 Dec 18; 8(6): 1146-50. [DOI: 10.3980/j.issn.2222-3959.2015.06.12]. eCollection 2015.
5. Mazoteras P, Casaroli-Marano RP. In vitro biofilm distribution on the intraocular lens surface of different biomaterials. J Cataract Refract Surg. 2015 Sep; 41(9): 1980-8. [DOI: 10.1016/j.jcrs.2015.05.029]
6. Fujita S, Tanaka T, Miyata A, Hirose M, Usui M. Cell adhesion and glistening formation in hybrid copolymer intraocular lenses. Ophthalmic Res. 2012; 48(2): 102-8. [DOI: 10.1159/000335981]. Epub 2012 Apr 18.
7. Krall EM, Arlt EM, Jell G, Strohmaier C, Bachernegg A, Emesz M, Grabner G, Dexl AK. Intraindividual aqueous flare comparison after implantation of hydrophobic intraocular lenses with or without a heparin-coated surface. J Cataract Refract Surg. 2014 Aug; 40(8): 1363-70. [DOI: 10.1016/j.jcrs.2013.11.043].
8. Krall EM, Arlt EM, Jell G, Strohmaier C, Moussa S, Dexl AK. Prospective Randomized Intraindividual Comparison of Posterior Capsule Opacification After Implantation of an IOL With and Without Heparin Surface Modification. J Refract Surg. 2015 Jul; 31(7): 466-72. [DOI: 10.3928/1081597X-20150623-05].
9. Harrer A, Hirnschall N, Maedel S, Findl O. Influence of the overall intraocular lens diameter on rotational stability. Ophthalmic Res. 2015; 53(3): 117-21. [DOI: 10.1159/000368658]. Epub 2015 Feb 7.
10. Bozukova D, Pagnoulle C, Jérôme C. Biomechanical and optical properties of 2 new hydrophobic platforms for intraocular lenses. J Cataract Refract Surg. 2013 Sep; 39(9): 1404-14. [DOI: 10.1016/j.jcrs.2013.01.050]. Epub 2013 Jul 2.
11. Poyales F. Comparision of the two IOLs with the same optics, two designs, two materials. ESCRS 2014.
12. Vock L, Menapace R, Stifter E, Findl O, Georgopoulos M. Clinical effects of primary posterior continuous curvilinear capsulorhexis in eyes with single-piece hydrophilic acrylic intraocular lenses with and without haptic angulation. J Cataract Refract Surg. 2007 Feb; 33(2): 258-64.
13. Schmidbauer JM, Escobar-Gomez M, Apple DJ, Peng Q, Arthur SN, Vargas LG. Effect of haptic angulation on posterior capsule opacification in modern foldable lenses with a square, truncated optic edge. J Cataract Refract Surg. 2002 Jul; 28(7): 1251-5.
14. Potvin R, Kramer BA, Hardten DR, Berdahl JP. Toric intraocular lens orientation and residual refractive astigmatism: an analysis. Clin Ophthalmol. 2016 Sep 20; 10: 1829-1836. eCollection 2016.
15. Jeon JH, Hyung Taek Tyler R, Seo KY, Kim EK, Kim TI. Comparison of refractive stability after non-toric versus toric intraocular lens implantation during cataract surgery. Am J Ophthalmol. 2014 Mar; 157(3): 658-65.e1. [DOI: 10.1016/j.ajo.2013.12.003]. Epub 2013 Dec 7.
16. Mainster MA. Violet and blue light blocking intraocular lenses: photoprotection versus photoreception. Br J Ophthalmol. 2006 Jun; 90(6): 784-92.
17. Bandyopadhyay S, Saha M, Chakrabarti A, Sinha A. Effect on contrast sensitivity after clear, yellow and orange intraocular lens implantation. Int Ophthalmol. 2016 Jun; 36(3): 313-8. [DOI: 10.1007/s10792-015-0120-4]. Epub 2015 Aug 19.
18. Jones JJ, Chu J, Graham J, Zaluski S, Rocha G. The impact of a preloaded intraocular lens delivery system on operating room efficiency in routine cataract surgery. Clin Ophthalmol. 2016 Jun 17; 10: 1123-9. [DOI: 10.2147/OPTH.S107726]. eCollection 2016.
19. Lombardo M, Talu S, Talu M, Serrao S, Ducoli P. Surface roughness of intraocular lenses with different dioptric powers assessed by atomic force microscopy. J Cataract Refract Surg. 2010 Sep; 36(9): 1573-8.
20. Pandita D, Vasavada A. Contrast sensitivity and glare disability after implantation of AcrySof IQ Natural aspheric intraocular lens. J Cataract Refract Surg. 2007;33:603-610.
21. Tzelikis, PF. Ocular aberrations and contrast sensitivity after cataract surgery with AcrySof IQ intraocular lens implantation. J Cataract Refract Surg. 2007;33:1918-1924.
22. Lane SS, Javitt JC, Nethery DA, Waycaster C. Improvements in patient-reported outcomes and visual acuity after bilateral implantation of multifocal intraocular lenses with +3.0 diopter addition: multicenter clinical trial. J Cataract Refract Surg. 2010;36:1887-1896.
23. de Vries NE, Webers CA, Montés-Micó R, Ferrer-Blasco T, Nuijts RM. Visual outcomes after cataract surgery with implantation of a +3.00 D or +4.00 D aspheric diffractive multifocal intraocular lens: Comparative study. J Cataract Refract Surg. 2010;36:1316- 1322.
24. Akella SS, Juthani VV. Extended depth of focus intraocular lenses for presbyopia. Curr Opin Ophthalmol. 2018;29:318–22.
25. Gatinel D, Loicq J. Clinically relevant optical properties of bifocal, trifocal, and extended depth of focus intraocular lenses. J Refract Surg. 2016;32:273–80.
26. John A. Vukich, M.D. Synchrony IOL shows long-term accommodative ability.ASCRS 2010.
27. Roibeard O'heineachain. Iol gives broader range of focus. https://www.eurotimes.org. 01-Apr-2019
28. Dimitra M Portaliou, George D Kymionis. The WIOL-CF accommodative intraocular lens. DOI: http://doi.org/10.17925/EOR.2009.03.01.54
29. Ben-nun J, Alió JL. Overview of the NuLens accommodating IOL. Cataract & Refractive Surgery Today Europe. 2008;3(1):20–21.
30. David F ChangAdjustable IOLs - disrupting the refractive IOL industry. DOI: https://doi.org/10.17925/USOR.2017.10.02.95.
31. Suresh K Pandey, Vidushi Sharma. Pearls for Piggyback IOL Implantation. DOI:http://dx.doi.org/10.7869/djo.3802-JAN-2014.
32. Fred Gebhart. New IOL design trends avoid negative dysphotopsias.https://www.ophthalmologytimes.com. October 4, 2019.
33. Bereczki Á. Experiences with the Scharioth Macula Lens - new hope for patients with dry macular degeneration. Rom J Ophthalmol. 2019 Apr-Jun;63(2):128-134. PMID: 31334390; PMCID: PMC6626938.
34. Giers, B.C., Khoramnia, R., Varadi, D. et al. Functional results and photic phenomena with new extended-depth-of-focus intraocular Lens. BMC Ophthalmol 19, 197 (2019).

    https://doi.org/10.1186/s12886-019-1201-3.