Theme section

Classification of Intraocular Lenses

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Abstract *This article aims at providing a synopsis of intraocular lenses which are being used in the present practice. The types have been classified based on structure, sites of fixation, optic and haptic material, Focality and also asphericity. The article also emphasizes the IOLs which have special functions and are used in uncommon situations. Future designs and newer concepts are being introduced every year owing to the advancements in our field.*

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***Keywords:** Intraocular Lenses, PMMA, Anterior Chamber IOL, Posterior Chamber IOL.*

Introduction

The history of replacing the cataractous lens with an intraocular lens to eliminate the "first complication of cataract surgery" i.e., Aphakia dates back to Casanova(1750s).[1-3]

The first successful IOL implantation was done by Sir Harold Ridley on November 29, 1949. The Inspiration stems from a simple question by a medical student about replacing the lens after removal. Sir Harold Ridley's sharp observation helped him choose the inert material when he noticed no deleterious effects from stationary particles of PMMA in the eyes of Royal Air Force pilots who sustained injuries from shattered spitfire during World War.[2]

IOLs were invented to treat the refractive error following cataract surgery. However, they are now being used to provide the patient with additional features and better visual quality. In this article, an overview of the types of intraocular lenses is provided.

Evolution of Intraocular Lenses

Following generations4 of IOLs have been invented since then and the development is still going on.

Generation 1: Sir Ridley posterior chamber IOL
Generation 2: Early anterior chamber lens
Generation 3: Iris-supported lenses
Generation 4: Modern anterior chamber IOLs
Generation 5: Rigid posterior chamber lenses
Generation 6: Foldable IOLs
Generation 7: Multifocal IOLs
Generation 8: Accommodative IOLS

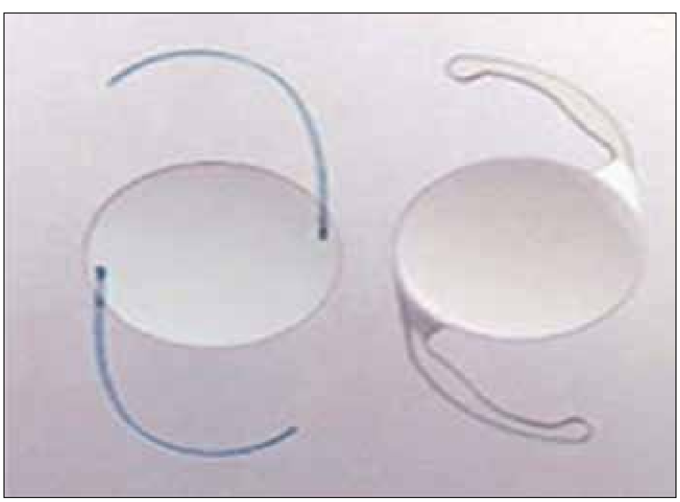

***Figure 1:** Alcon AcrySof Multi-piece (left) Single piece (right)*

A special mention about the most important change in the newer anterior chamber IOLs which significantly reduced the complications with older designs was the change in the haptic design. The haptic of the Multiflex was distinctive in its structure that it allowed flexion in the same plane as the haptics avoiding anterior movement of the optic.

Classification Of Types Of Intraocular Lenses

1) Types based on IOL construction

- **Single piece design:** The whole lens has been constructed from the same material (Figure 1).
- **Multi-piece design:** The haptics and the optic are made up of different materials.

Optics Edges

- Round-edged IOLs
- Square-edged IOLs

Various studies have shown that a square posterior optic edge is associated with better results in preventing posterior capsule opacification (PCO). It can be attributed to many mechanisms

1) Mechanically preventing migration (Figure 2)
2) Contact inhibition of migrating lens epithelial
3) Higher pressure over posterior capsule with square edge

Maximal prevention of PCO can be achieved when the square edge is present for the whole circumference of the optic. Single piece designs in which the junction has an even transition the square edge effect is lost and may lead to the starting of PCO.[5]

Not only the posterior edge but the design of the sidewall of the optic edge is important. Unpolished or "textured" sidewalls had lower rates of glare compared to the smooth ones.[5]

Optic-haptic junction

Angulation between the optic and the haptic is responsible for the stability of the IOL and also to prevent complications. Posterior angulation increases the contact between the lens and capsule hence preventing PCO formation. When an IOL is placed in the ciliary sulcus this angulation provides sufficient space between the lens and iris preventing rubbing.[5]

A. Single piece IOL with 0° angle: Smooth transition at junction and PCO can start at these junctions.
B. Single piece with step-vaulted design: The haptic is shifted anteriorly from the plane of the optic which

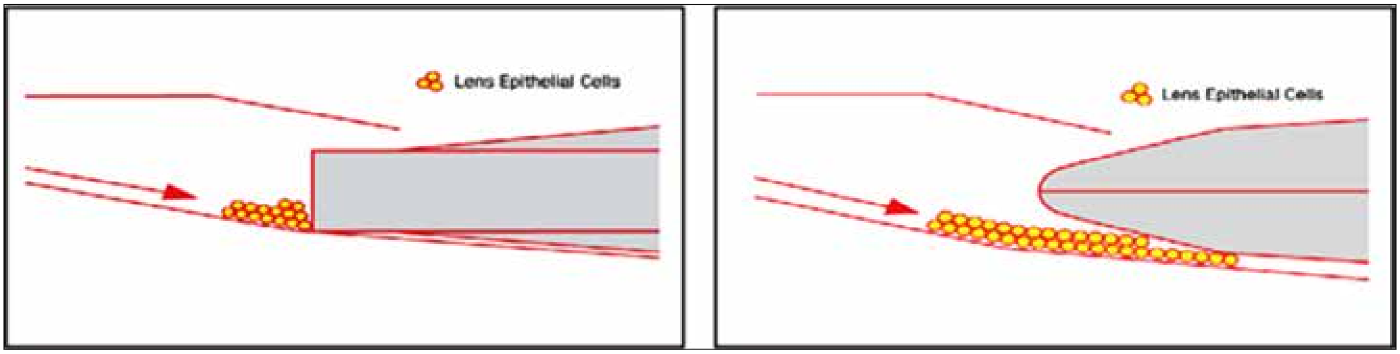

***Figure 2:** Square edge blocking the migration of lens epithelial cells(left) compared to the round edge(right) Image courtesy: Findl, Oliver. "Intraocular Lens Materials and Design."*

allows the optic to have a 360° square edge and hence prevents PCO formation.

C. 3-piece lenses: Angulation of up to 10° provides sufficient pupillary clearance and adhesion to the posterior capsule.[5]

2) Types based on site of Fixation

IOLs can be placed in the anterior or posterior chamber depending upon the status of the capsular bag.

- **Anterior Chamber**

Angle: These IOLs are placed in an eye which has a healthy iris and adequately deep chamber but lacks an intact capsule. The most widely used ACIOL is the Kelman Multiflex design (Figure 3). This newer design is better in terms of fewer chances of complications like secondary glaucoma, pseudophakic bullous keratopathy, and cystoid macular oedema compared to older designs. The size of the lens is selected by adding 1mm to the white-to-white distance.[5]

Iris: Rigid one-piece PMMA lenses. These are fixated on the iris stroma with claws. An example is the Artisan aphakic lens (Ophtec, Netherlands)(Figure 4). Iris enclavation is done with the help of a special instrument.

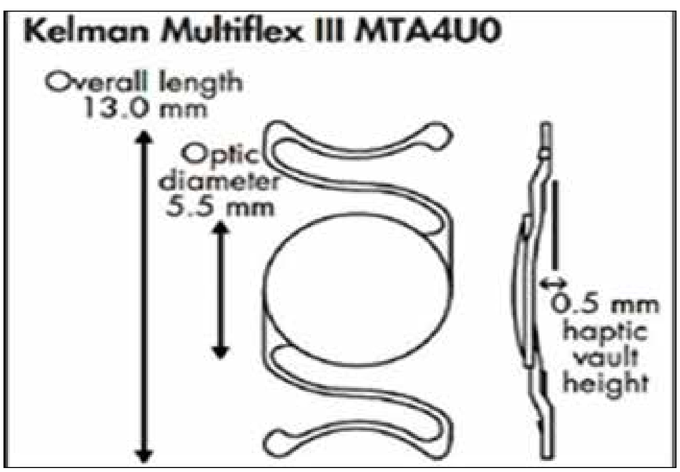

***Figure 3:** Schematic of the Kelman Multiflex III ACIOL (Image by Alcon Laboratories,Inc.)*

There are two types:

Pre-pupillary iris-claw lenses: These IOLs are associated with more corneal complications and are less commonly used

Retro-pupillary iris-claw lenses: Fixated behind the iris and have fewer complications and are cosmetically more accepted.

- Posterior Chamber

Capsular bag: Ideal site of fixation for posterior chamber IOLs. Prevents PCO formation, tilting, decentration and uveal tissue rubbing. Minimal magnification and safer in children and young adults.

Ciliary sulcus: IOL is placed in this position when the integrity of the posterior capsule is compromised but the residual capsular support is enough to support the lens. To prevent uveitis-glaucoma-hyphema syndrome angulated IOLs preferably a 3-piece IOL with sufficient iris clearance should be used. A posterior optic capture can also be performed if a central and adequately sized rhexis is present which ensures centration and avoids rubbing over the iris.[5]

***Figure 4:** Artisan iris-claw ACIOL (Image by Ophtec BV)*

3) Types based on IOL Material

Optic material

1) Rigid IOLs

Since the Ridley era, PMMA is the commonest material used for the manufacturing of IOLs. It is rigid, chemically inert and has a higher refractive index (1.49) which helps to make thinner and lighter lenses. The material has excellent optical properties and laser resistance. Since it's a rigid lens larger incisions are required.[6]

2) Foldable IOLs

a. Silicone IOLs

The material is hydrophobic. It has a lower refractive index and thus the IOLs are thicker. These IOLs are difficult to handle with poor control during implantation. The risk of silicone oil adhesion is high6. However, the chance of PCO formation is low.

b. Hydrogel IOLSs

The material swells in water. Made up of polyhydroxyethl methacrylate and has a water content of about 18%.

c. Acrylic IOLs

i. Hydrophilic

It is a mixture of hydroxyethylmethacrylate and a hydrophilic acrylic monomer. 18-26% water content with a contact angle of lower than 50°. Easy handling but the risk of PCO formation is higher.

ii. Hydrophobic

Copolymers of acrylate and methacrylate. Minimal water absorption and contact angle of >70° with a higher refractive index of 1.44-1.556 ensuring thinner IOLs. It has good resistance to YAG laser and has significantly lower chances of PCO formation compared to other IOL materials

3) Rollable IOLs

IOLs are implanted in Microincision Cataract surgery (MICS) through a ≤ 2mm incision. The term 'Phaconit' means phacoemulsification (phaco) with a needle (N) opening via an incision (I) and with the phaco tip (T). This concept of surgery through 0.9mm incision was publicised by Dr Amar Agarwal.[7]

Examples:

- Acri.Smart™ lens
- Ultrachoice 1.0 rollable thin lens
- Slimflex lens

Haptic material[5]

Materials which are being used for the production of the haptics of 3-piece lenses are:

a. PMMA
b. Polypropylene (Prolene)
c. Polyamide
d. Polyvinylidene fluoride (PVDF)
e. Polyethersulfone (PES)

4) ASPHERIC IOLs[8]

Spherical aberration (SA) is one of the higher-order aberrations (HOA), however, it affects the quality of the vision the most. When the peripheral rays of light focus in front of the central rays, it is called positive SA and if behind the central rays, it is negative SA. The normal SA value of the cornea is positive which does not change much with the ageing process. The SA value of the young crystalline lens is negative which balances the corneal spherical aberration.

With the ageing process, there is a shift of negative SA value in the crystalline lens to positive. When we implant an IOL with positive SA the total SA increases which decrease the contrast sensitivity8.With the advances in technology, there is the availability of Aspheric IOLs which balance the SA of the cornea and give better optical quality, especially in low light and low contrast situations.

Following are the FDA approved aspheric IOLs:

- **TechnisZ9000 (Advanced Medical Optics)**

Negative SA value of 0.27 um with an anterior prolate surface

- **AcrySof IQ**

Negative SA value of 0.20 um with a posterior prolate surface

- **Sofport AO**

SA value of zero which does not contribute to any pre-existing HOA and has both anterior and posterior prolate surface

5) Premium IOLs

A. Multifocal IOLs

The optics of multifocal IOLs are designed to focus on distance as well as near. The technology works on the brain's ability to select the clearest image presented to it.

There are two types:

Refractive optics multifocal IOLs

The refractive IOLs have annular zones of different powers which provide the focus for far and near. They provide a better intermediate and distant vision while the near vision may not be sufficient. These IOLs are pupil-dependent, sensitive to minimal decentration, intolerant to change in angle kappa, higher rates of glare and halos and also provide low contrast sensitivity.[9]

Refractive IOLs are available in two styles:

1) Two-zone lenses: Central near vision segment and peripheral distance vision segment
2) Annulus type: Central distant vision surrounded by near vision, surrounded by distant vision ring (Figure 5).

Examples:

- Array multifocal IOL (AMO)
- ReZoom multifocal IOL (AMO)
- PREZIOL (Care Group)

Diffractive optics multifocal IOLs

These lenses are based on the principle of diffraction which states that each point of a wavefront can function as its source of secondary wavelets9, When diffractive microstructures are placed in concentric zones with decreasing distance as they move towards the centre, a Fresnel zone plate is

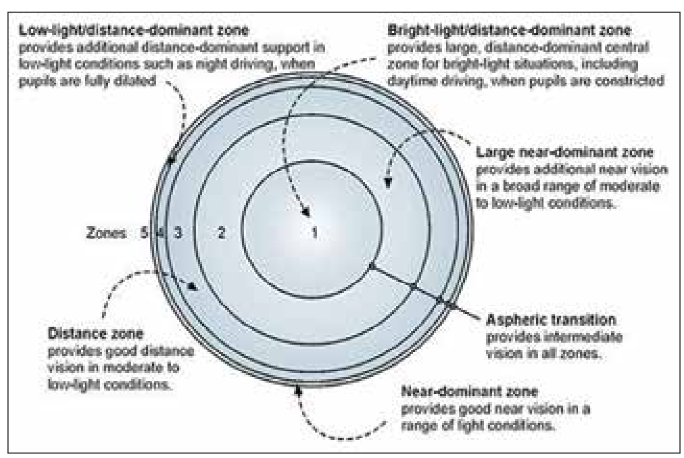

Figure 5: Annulus refractive IOL (Image from Lane, Stephen, Mike Morris, Lee T. Nordan, Mark Packer, Nicholas Tarantino and R. Bruce Wallace. "Multifocal intraocular lenses." Ophthalmology clinics of North America 19 1 (2006))

produced which can produce optic foci (Figure 6).[9]

Diffractive IOLs lose 18% of light and divide the remaining light into two foci, 41% for distance and 41% for near. These IOLs provide excellent distance and near vision but an acceptable intermediate vision.

Apodization solves the problem of poor intermediate vision to some extent. The apodised IOLs have a gradual decrease in diffractive step from centre to periphery that creates a smooth transition of light between the focal points which increases the quality of intermediate vision.

Example: iDIFF plus and AcriDIFF

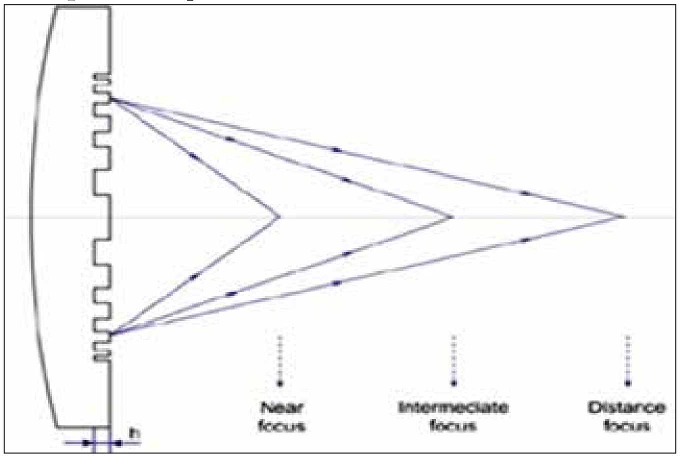

Figure 6: Diffractive IOL principle (Image from Voskresenskaya A, Pozdeyeva N, Pashtaev N, Batkov Y, Treushnicov V, Cherednik V. Initial results of trifocal diffractive IOL implantation. Graefes Arch Clin Exp Ophthalmol. 2010 Sep;248(9):1299-306)

Diffractive IOLs are less pupil-dependent and can tolerate angle kappa and decentration. These IOLs have more chances of producing glares and halos and the main disadvantage is the loss of light due to scattering.

Examples:

- Tecnis Multifocal IOLs (AMO)
- Acrysof IQ ReSTOR (Alcon)
- Panoptix (Alcon)(Figure 7)

Extended Depth of Focus (EDOF) IOLs

EDOF lenses create a single elongated focal point to enhance the depth of focus. Two technologies are used:

1) Diffractive optical design
2) Achromatic technology reduces the eye's natural chromatic aberration

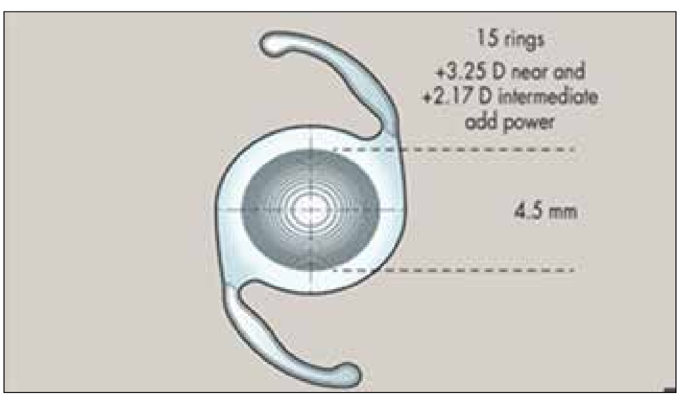

Figure 7: Panoptix IOL (Image from Kohnen T. First implantation of a diffractive quadrafocal (trifocal) intraocular lens. J Cataract Refract Surg. 2015 Oct;41(10):2330-2)

The IOLs have an aspheric anterior surface and posterior achromatic diffractive surface. Example:

- TECNIS Symfony (AMO)(Figure 8)
- AcrySof IQ Vivity

EDOF lenses improve the distance, intermediate and near vision. EDOF lenses also preserve contrast sensitivity10.

EDOF lenses provide excellent distance and intermediate vision but are less efficient for near vision when compared to Trifocals.

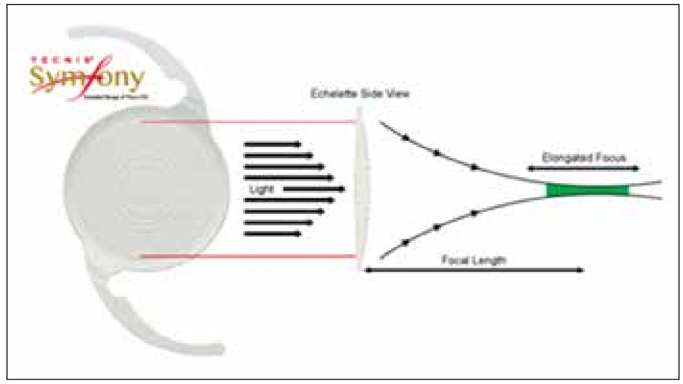

Figure 8: Tecnis Symfony IOL

B. Accommodative IOLS

Accommodative IOLs have been developed based on Helmholtz's theory of accommodation. The theory states that with contraction of ciliary muscle there is zonular laxity which allows the lens to increase its anteroposterior diameter hence increasing the dioptric power.

The following approaches are being used to restore accommodation:

A. Change in axial position

a. Single optic

The basic mechanism behind these IOLs is the forward movement of the optic and variation of radius of curvature of the anterior surface.[11]

Example:

i. Crystalens HD (B&L) (Figure 9)

Figure 9: Crystalens IOL (Image from Alió JL, Plaza-Puche AB, Montalban R, Javaloy J. Visual outcomes with a single-optic accommodating intraocular lens and a low-addition-power rotational asymmetric multifocal intraocular lens. J Cataract Refract Surg. 2012)

ii. Tetraflex
iii. 1CU

b. Dual Optic

The anterior component has a high plus power and the posterior component has a minus power to make the eye emmetropic. Two components are connected by a bridge with spring action11. The IOL is not available commercially. Example: Synchrony (Visiogen Inc.)(Figure 10).

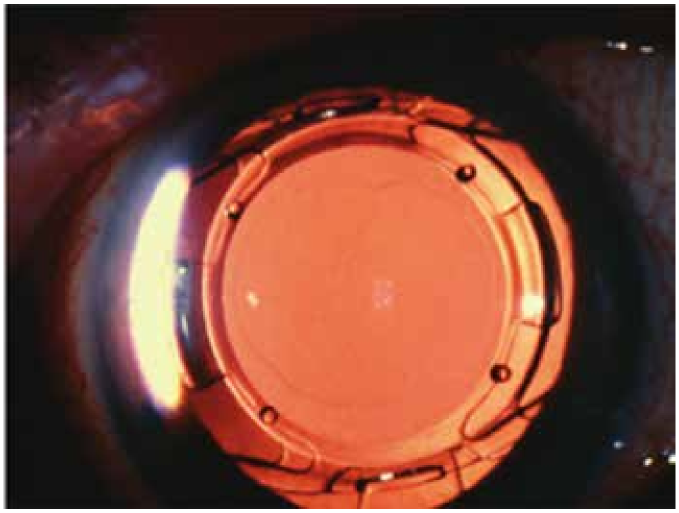

Figure 10: *Synchrony IOL (Image from Dick HB. Accommodative intraocular lenses: current status. Curr Opin Ophthalmol. 2005 Feb;16(1):8-26*

B. Change in shape or curvature

a. FluidVision[13]

The Haptic and interior of the optic are filled with silicone oil. It is designed in such a way that while accommodating the silicone oil migrates from the haptic into the optic and the anteroposterior diameter of the optic increases which increases the dioptric power.

b. NuLens[12]

PMMA haptics and PMMA reference plane with a small chamber that contains solid silicone oil with a posterior piston. When the piston is pressed the silicone gel bulges. The IOL is not available commercially.

C. Change in refractive index or power

a. Lumina

The IOL has two optical elements and both have a U-shaped elastic loop with a spring action which is connected to the optic via a non-elastic element. When the ciliary muscle contracts the optics move in the opposite direction and the optical power of the lens increases.

C. Toric IOLS

Toric IOLs are astigmatism correcting IOLs and are indicated in patients with ≥ 1.0D of regular astigmatism. Standard toric lenses are available in cylinder powers of 1.5D to 6D.[14] They are available as monofocal and multifocal lenses.

» For the calculation of IOL power, standard websites of various companies are available.
» Preoperative marking of the axis, central rhexis and thorough removal of OVD is very essential.
» The correction effect of toric IOLs decreases when they rotate off-axis. When AcrySof toric rotates by 3°, 10% of the correction effect is reduced. The full effect is lost when IOL rotates by 30°.

Multifocal toric	Multifocal toric
AcrySof Toric IOL	AcrySof IQ ReSTOR
Hoya iSert Toric 351	Tecnis Symfony Toric
Staar Toric IOL	EnVista toric IOL
AMO Tecnis Toric IOL	

6) Special function IOLs

A) Aniridia IOLs

Aniridia is the absence of iris tissue. It can be congenital or traumatic. Associated cataract and weak zonules are present in 50-85% of patients with congenital aniridia. Aniridia IOLs are available for scleral fixation, ciliary sulcus placement and also endocapsular insertion in patients who have a normal capsule.

The lens has a central clear zone which corrects the refractive error and a peripheral opaque zone which reduces the entry of light and acts as an iris diaphragm. This diaphragm reduces glare and photophobia which is troublesome to patients with aniridia.[15]

B) Implantable miniature telescope IOLs

» Implanted in the posterior chamber
» Developed by VisionCare Ophthalmic Technologies (California)
» Microlenses magnify objects in the central visual field
» Indicated in patients with Age-related macular degeneration

C) Piggyback IOLs

In patients with nonophthalmic eyes, IOLs with very high powers are required which is not possible in a single IOL due to the thickness and reduced image quality due to spherical aberration. To combat this issue the concept of piggyback IOL was introduced.

One IOL is placed in the capsular bag and the second IOL is placed in the ciliary sulcus. Complications:

- Interlenticular opacification
- Unpredictable IOL position

Other special IOLs are Smart yellow IOLs and Blue blocking IOLs.

7) Phakic IOLs

In patients with high ametropia, the corneal refractive surgery has reduced safety, predictability and efficacy. Phakic IOLs provide us with predictable results and superior visual outcome and also preserves the cornea.

Phakic IOLs are indicated in moderate to high myopia, high hypermetropia and high astigmatism16. Three varieties of Phakic IOLs are available based on the site of fixation:

I. Angle supported lenses

- **AcrySof Cachet –** single-piece foldable, soft hydrophobic acrylic phakic IOL.
- **Kelman duet –** The duet consists of a separate PMMA

tripod haptic which is implanted first and the foldable optic is inserted after that which is fixed to the haptic with the help of a Sinskey hook.
These lenses have a higher risk of pupillary ovalisation, endothelial cell loss and elevation of IOP.

II. Iris-fixated lenses

- Artisan iris-claw (Ophtec)
- Verisyse (AMO)

The lens is fixated on the mid-peripheral iris which renders it immobile during pupillary movements.
It is associated with pigment dispersion, endothelial loss, glaucoma, iris atrophy, dislocation and also cataract formation.

III. Posterior chamber lenses

- PRL (IOLTech/CIBA Vision)
- ICL (Implantable collamer lens- STAAR Surgical Co.)

These are associated with lower rates of complications with excellent visual outcomes.

8) Future IOL designs

A. Injectable gel IOLs

Femtosecond assisted cataract surgery allows us to remove the cataract through a small incision and allows us to inject the IOL in the gel form. This research began in 1986 at the Bascom Palmer Eye Institute. The technology has the possibility of restoring accommodation.

B. Light adjusted IOLs

A Noble-prize-winning technology allows us to change the refractive power of the lens after implantation. The lens has been developed by Roy freeman of RxSight. The IOL is made up of special macromers. When these macromers are exposed to the light of a specific wavelength they get photopolymerised.

Myopia, Hypermetropia and even astigmatism can be treated with these lenses.
Once the adjustment is done the entire lens is irradiated to polymerize and fix the remaining macromers.

C. Intraocular pressure sensor implanted with IOL

High-tech innovation which is implanted during cataract surgery. It is a microelectronic sensor that measures intraocular pressure.[17]

Example:

Eyemate (Implandata Ophthalmics Products GmbH)

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