Chapter

Basic Science of Intraocular Lens Materials

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Abstract

This chapter will explain the materials used in making intraocular lenses. Rigid IOL's made of PMMA have now given way to foldable silicone and acrylic lenses. This chapter will also throw light on the indications and contraindications for using each of the IOL's. The composition of each of the lenses, their water content, mechanical properties and their special ultraviolet absorbing features will be discussed in detail. The mechanism by which hydrophilic lenses are inserted through small incisions during cataract surgery will need a special mention. The problems with use of different types of intraocular lenses will also be dealt with.

Keywords: intraocular lens, material, PMMA, acrylic, silicone

1. Introduction

Cataract surgery is being carried out for over more than 3000 years. What began as simply dislodging the cataractous lens posteriorly into the vitreous, also known as couching, got the ball rolling. And now we have advanced surgical techniques with minimal incision size and excellent visual prognosis due to the recent advances in intraocular lenses (IOL) [1].

In November, 1949, Dr. Harold Ridley implanted the first intraocular lens after extracapsular cataract extraction (ECCE) in a 45 year old female at St. Thomas Hospital, London [2]. This IOL was made of a material called Polymethylmethacrylate (PMMA).

After a lot of clinical trials and initial disapproval, it wasn't until 1970, that IOL implantation became a well accepted procedure. And hence began a revolution in the field of cataract management. Over the past 5 decades there have been monumental breakthroughs and various IOLs of finest elements are now routinely being implanted (**Figure 1**).

An intraocular lens can be described on the basis of certain properties possessed by the material it is made up of. These properties include the following:

1. Affinity for water

2. Refractive index

3. Size of optic and haptic

4. Adhesiveness

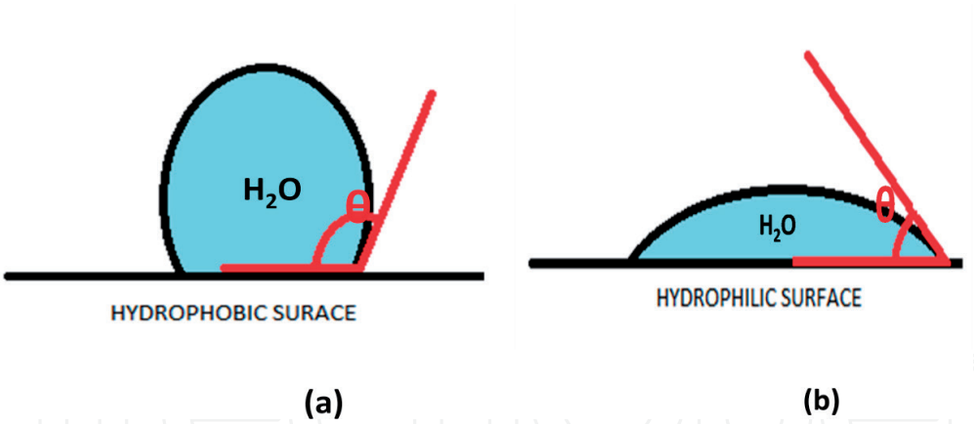

Figure 1.
Contact angles of water on hydrophobic and hydrophilic surfaces. (a) Contact angle is >90° on hydrophobic surface (b) contact angle is <90° on hydrophilic surface.

5. Presence or absence of glistening phenomenon

6. Prevention of posterior capsular opacification (PCO)

7. IOL design

1.1 Affinity for water

IOL materials are defined hydrophobic or hydrophilic according to the angle a drop of water makes with respect to the material surface. The more acute this angle is, the more hydrophilic the material is defined and vice versa.

1.2 Refractive index

Refractive index of a material refers to ratio of velocity of light in vacuum to velocity of light in that medium. It is a measure of bending of light rays when they travel through a particular medium. The refractive index and thickness of the IOL are inversely proportional.

1.3 Size

The optic diameter and the length of the haptics are taken into consideration when the size of the IOL is to be measured. The size of the incision, the type of injector and methods of introducing the IOL are all based on the size of the IOL.

1.4 Adhesiveness

Adhesiveness is a property by which the IOL fuses with anterior and posterior capsule and hence reduces the risk of decentration. This property becomes essential in toric IOLs.

1.5 Glistening phenomenon

Penetration by aqueous humor has been noted to cause small vacuoles within the lens optic. This phenomenon is called 'glistening phenomenon'.

1.6 Prevention of PCO

The properties of the IOL such as affinity for water, adhesiveness and presence of square edge contribute in prevention of opacification of posterior capsule after cataract surgery.

1.7 IOL design

The structure and design of IOL contributes to its ability to remain centered in the capsular bag. The shape and length of haptics and the optical diameter are taken into consideration in designing an intraocular lens.

2. Classification

Based on the materials, intraocular lenses can be classified as:

1. Rigid (PMMA)

2. Flexible (Silicone)

3. Foldable (Acrylic)

4. Collamer

2.1 PMMA

One of the first materials to be used for the purpose of intraocular lenses, polymethyl methacrylate (PMMA) is a rigid, non-foldable, hydrophobic material (**Figure 2**). Hydrophobic nature of PMMA lenses makes them more likely to adhere to corneal endothelial cells during insertion, thus causing potential endothelial loss. The refractive index is 1.49 and the usual optic diameter is 5–7 mm. They are usually single piece and have low memory haptics.

Due to their property of rigidity, a large incision is required for its implantation. An incision size of about 5.5–6 mm or a large corneoscleral tunnel is required for its

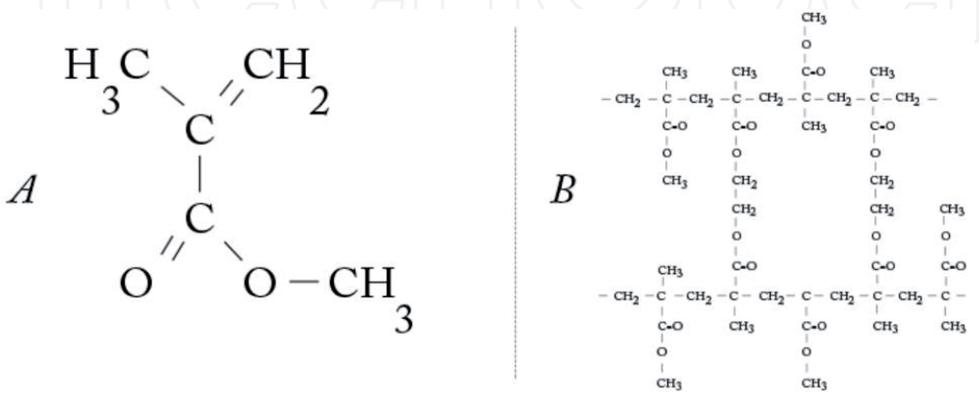

Figure 2.
(a) MMA (methyl methacrylate) forms the basis for acrylic IOLs. (b) Poly(methyl methacrylate) (PMMA) is a transparent thermoplastic; it was initially developed as a lightweight and shatter-resistant alternative to glass.

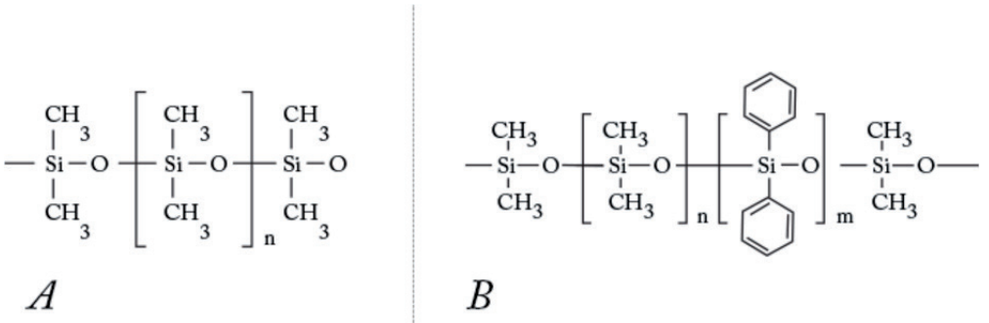

Figure 3.
(a) Polydimethylsiloxane and (b) polydimethyldiphenylsiloxane.

implantation. Large sized incisions are associated with delayed healing and astigmatic refractive errors. Hence PMMA is seldom used today except in developing countries due to economic reasons.

One piece variant of PMMA lens means that optics and haptics are made from a single mold of the same material. It is said to be three piece when the optics and the haptics are made from different materials and are attached together (**Figure 3**).

Penetration by aqueous humor has been noted to cause small vacuoles within the lens optic. This "glistening" phenomenon is rarely seen with PMMA.

After the advent of phacoemulsification in 1967, by Charles Kelman, the size of the incision did decrease significantly. However, the incision still had to be extended for implantation of the rigid IOL. The obligation of downsized incision was still amateur. This made way for the flexible and foldable breed of IOLs.

2.2 Silicone

Since 1950s, silicone has been used in a variety of medical device applications including contact and intraocular lenses. The malleable nature of silicone makes it chemically stable as well as imparts diverse mechanical properties. Also, due to its excellent biocompatibility and versatile properties, desired optical clarity and specific viscosity can be attained.

The first foldable silicone IOL was implanted in human eyes in the 1978 by Kai-yi Zhou. Silicone is hydrophobic, that is, it makes a contact angle of 99^0 with the water droplet on its material surface and therefore must be handled dry before implantation. This property allows a smaller incision than the IOL size. The refractive index of silicone lens is between 1.41 and 1.46 and the optic diameter is 5.5–6.5 mm. Because of the low refractive index, the optics are rather thick especially for high refractive powers. Such lenses may require an incision of size up to 3.2 mm. Although there are injectors available for safe and dry handling of silicone lenses, premature and abrupt opening of the lenses remains a dispute for most surgeons.

After implantation, the anterior capsule rim opacifies quickly, while the posterior capsule may remain clear for many years. Despite the low posterior capsular opacification (PCO) rate and the good resistance to Nd:YAG laser shots, silicone is less used today because it is not suitable for micro incision cataract surgery (MICS).

Adhesiveness is a property by which the IOL fuses with anterior and posterior capsule and hence reduces the risk of decentration. An important point about silicone lenses is that it has poor adhesive property and it is kept in place by the virtue of its haptics and capsule coalescence. The character of "glistening" is seen in silicone lenses as well.

Silicone lenses are available in two variants depending on the type of haptics. The two kinds of haptics include modified C loop and plate haptics. Of these, the plate haptics have a higher tendency to decenter in eyes with defective anterior capsule [3].

Silicone is a synthetic polymer made up of periodically repeated silicon-oxygen-groups (siloxane). This structure is the backbone for a polymer, which is identical for all silicone IOLs. Bound to the silicon atom are side chains, which influence the properties of the material.

2.3 Acrylic

The rigid PMMA lens is acrylic in nature. However the side chain molecules attached to the main polymer confer certain properties to the IOL. So, substituting the side chains in PMMA to hydroxyethyl or polyethyl groups alters the rigidity of the material. The newly formed polymers are now flexible and clear and this is the material that makes newer generation IOLs foldable. Furthermore, depending on the side-chain chemistry, the flexible acrylic material can be made to be hydrophilic or hydrophobic.

Most hydrophilic IOLs utilize the same material as contact lenses: hydroxyethylmethacrylate (HEMA) (**Figure 4**). Poly HEMA containing IOLs are also called hydrogels. With a water content of approximately 38%, they are flexible. Because of the high water content, they have a low refractive index. These lenses are highly foldable and can be injected through incisions approximately 1.8 mm in length or smaller, allowing for microincision cataract surgery (MICS). Because of hydrophilic nature of hydrogels, they are flexible and inert. Hydrophobic lenses have a low water content (<1%) and they carry a lesser risk of posterior capsule opacification. Higher uveal biocompatibility was achieved with the modern hydrophilic acrylic IOLs than with the hydrophobic acrylic IOL [4].

A salient property of these acrylic materials is glass transition temperature or Tg. It is essentially the temperature at which the material changes its rigidity and becomes more flexible. Tg is different for different acrylic materials depending on its side chain molecule.

Foldable acrylic lenses tend to be more robust than their silicone equivalents. They undergo less post-implantation decentration or rotation. If posterior segment surgery is likely to be necessary at a later date, they are a better choice, as silicone oil – which would ruin silicone-based IOLs – can be used. However, this comes at the cost of a slightly larger incision size being necessary for implantation.

The three piece hydrophobic acrylic foldable intraocular lens consists of a truncated hydrophobic optic and polymethylmethacrylate (PMMA) haptics. The single piece IOL is a new version of the hydrophobic acrylic foldable IOL, with both

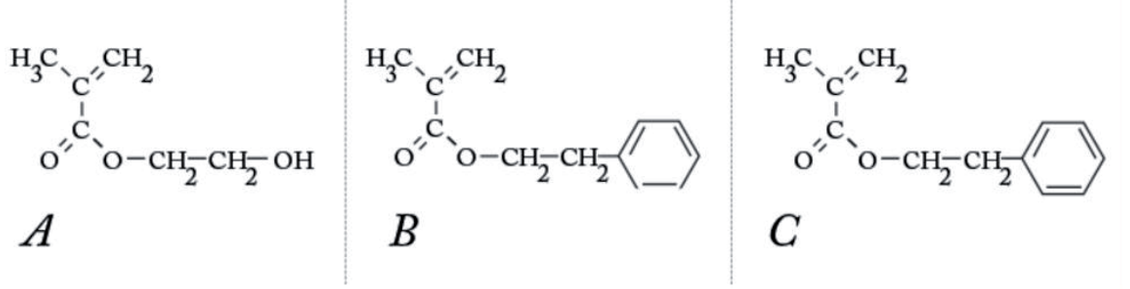

Figure 4.
Flexible acrylic lenses can be made from (a) HEMA – (hydroxyethyl) methacrylate, (b) PEMA – (polyethyl) methacrylate, and (c) PEA – poly(ethyl acrylate).

the optic and haptics consisting of a foldable acrylic material. The table below gives a comparison based on their different properties [5, 6]:

IOL Material	Advantage	Disadvantage
Hydrophilic acrylic	Higher tissue compatibility due to high water content Low aqueous flare Low rate of inflammatory cell accumulation on the lens surface	Insufficient posterior sharp-edged design due to the high water content High rate of posterior capsule opacification High rate of anterior capsule opacification Greater lens epithelial cell ongrowth on the lens surface
Hydrophobic acrylic	Material compatible with a posterior sharp-edged design Low rate of posterior capsule opacification Low rate of anterior capsule opacification Low rate of lens epithelial cell ongrowth on the lens surface	High aqueous flare* Inflammatory cell accumulation on the lens surface*
PMMA	Good tissue compatibility Low aqueous flare Low rate of inflammatory cell accumulation on the lens surface	Foldable High rate of posterior capsule opacification
Silicone	Low rate of inflammatory cell accumulation on the lens surface Low rate of posterior capsule opacification	Increased fibrotic reaction due to lens epithelial cell stimulation Lens surface opacification due to contact with intravitreal air Difficulty visualizing the retina due to interface formed with silicone oil used in vitreoretinal surgery

*Not at a clinically significant level
PMMA: Poly(methylmethacrylate), IOL: Intraocular lenses

Properties	Single piece acrylic	Three piece acrylic
Visual acuity	Same	Same
Refractive stability	Same	Same
Centration	Same	Same
SPCO formation	More	Less
Anterior capsule opacification	Less	More
Dysphotopsias	Less	More

	PMMA	Silicone	Acrylic
Size	5–7 mm	5.5–6.5 mm	Foldable (minimum 1.8 mm)
Rigidity	Rigid	Flexible	Foldable
Affinity to water	hydrophobic	hydrophobic	Hydrophilic/hydrophobic
Refractive index	1.49	1.41–1.46	1.39–1.42

2.4 Collamer

Another subset of hydrophilic foldable acrylics is the Collamer lens. This Collamer material is a patented copolymer of hydrophilic acrylic and porcine collagen (<0.1%) hydroxyethyl methacrylate copolymer with a UV absorbing chromophore. In theory, the porcine collagen improves the biocompatibility of the lens when implanted in human eyes. It is a foldable phakic IOL consisting of a plate haptic with a central convex/concave optical zone and a forward vault to reduce the contact with the lens.

3. Ultraviolet absorbing intraocular lenses

The crystalline lens absorbs ultraviolet radiation between 300 and 400 nm and protects the retina from photochemical damage [7]. This protective phenomenon is lost when the lens is removed during cataract surgery, but it can be restored by the implanting a UV-absorbing polymethylmethacrylate IOL. Implantation of a UV absorbing IOL results in cyanopsia or blue tinted vision. However it helps in preventing age related macular degeneration, improving contrast sensitivity and

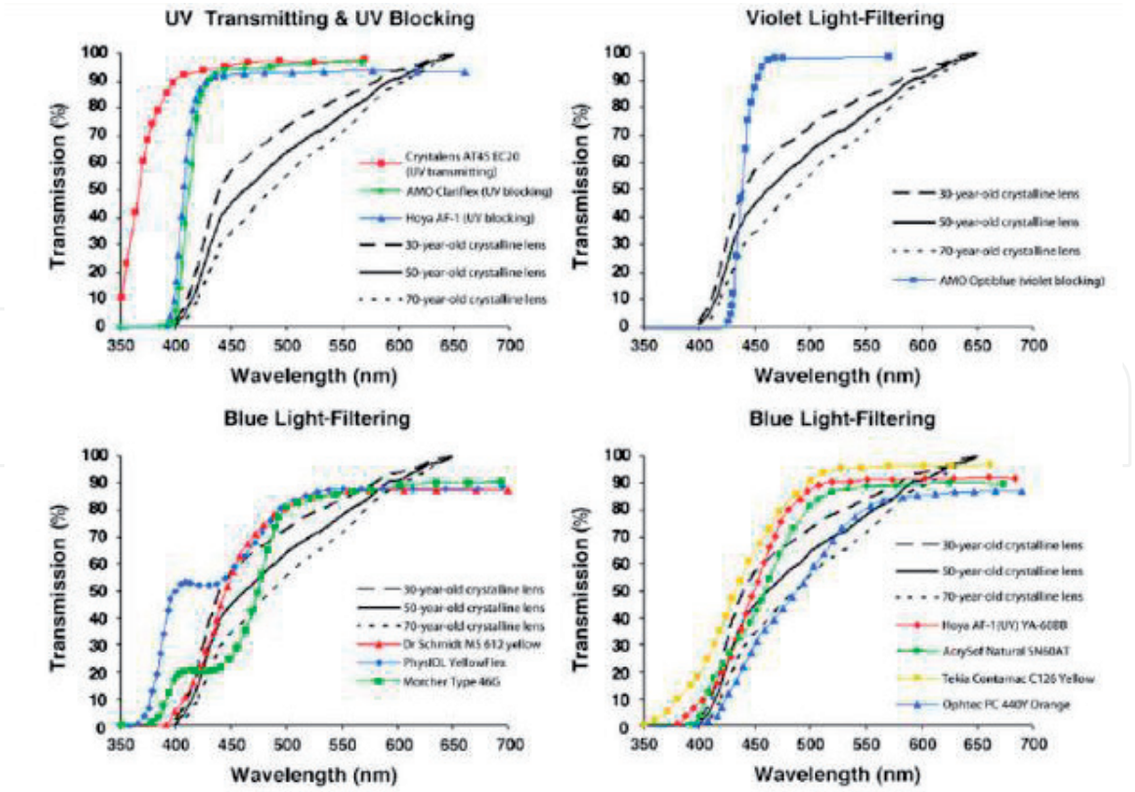

Figure 5.
Comparison of transmission spectra of UV transmitting, UV blocking, violet light-filtering and blue light-filtering IOLs [8, 9].

reducing glare in mesopic and photopic conditions. There are various UV-absorbing IOLs but they are not equally effective in absorbing UV radiation (**Figure 5**). To prevent the toxic effects of short wavelength light, IOL's have been developed that only block UV light but also reduce transmission of violet and blue wavelengths. The yellow pigment containing IOL's were first developed by Hoya in Japan followed by Menicon Co. Ltd. The first foldable IOL was developed by Alcon Laboratories.

4. Future aspects

The incidence of endophthalmitis following cataract surgery has reduced significantly over the last few decades but it is still a nightmare for every eye surgeon. Post-operative instillation of topical antibiotics and antiinflammatory is the rule. However, recent studies show that delivery of these drugs intraocularly released from the IOL material may reduce the need for postoperative medication and thereby may further reduce the incidence of endophthalmitis. A combination of moxifloxacin and ketorolac is better than a combination of moxifloxacin with diclofenac [10]. Its effective against *Staph. aureus* and *Staph. epidermidis* for about 15 days. Further studies should be aimed at such modern dual drug delivery incorporated in the IOL.

5. Summary

Right from couching and rendering the patient aphakic, science has come a long way to manufacturing intraocular lens. The different materials have their own advantages and pitfalls owing to their chemical structure and inherent properties. UV absorbing and dual drug delivery systems are the future.

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