“Update on Intraocular Lens Materials And Biocompatibility”

Liliana Werner, MD, PhD
Assistant Professor
With the collaboration of:

Nick Mamalis, MD  David J. Apple, MD
Suresh K. Pandey, MD  Brian Hunter, MD
Andrea M. Izak, MD  Jesse Chew, MD
Scott M. Hickman, MD  Mary Mayfield, HT
Russell LeBoyer, MD  James Gilman, CRA
Scott Stevens, MD  Beth Snodgrass, CRA

John A. Moran Eye Center
University of Utah
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

1) **Acrylic**

<table>
<thead>
<tr>
<th>Rigid</th>
<th>Foldable</th>
</tr>
</thead>
<tbody>
<tr>
<td>-PMMA</td>
<td>a) Hydrophilic</td>
</tr>
<tr>
<td></td>
<td>-Centerflex™</td>
</tr>
<tr>
<td></td>
<td>-MemoryLens™</td>
</tr>
<tr>
<td></td>
<td>-Hydroview™</td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>-Collamer™</td>
</tr>
</tbody>
</table>

2) **Silicone**


Biomaterials for the Manufacture of IOLs

- *Polymerization*: Repeating units (monomers) form a polymer

- Covalent, stable bonds

- Methyl methacrylate (monomer), poly (methyl methacrylate) (polymer)

- **PMMA**: rigid, linear acrylic polymer

- *Three-dimensional, flexible acrylic polymers*: cross-linking and copolymerization
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

1) **Acrylic**
   - **Rigid**
     - Poly(methyl methacrylate)
     - PMMA

![Chemical structure of PMMA](image)

![Examples of acrylic intraocular lenses](image)
1) **Acrylic**

- **Foldable**
- **Hydrophilic (hydrogels)**

-The material of each lens design is made from a different copolymer acrylic

- Water content ranging from 18% to 38%
- Refractive index ranging from 1.46 to 1.48
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

1) **Acrylic**
   - Foldable
   - Hydrophilic (hydrogels)

   ![Centerflex™](image1)
   ![MemoryLens™](image2)
   ![Hydroview™](image3)
Biomaterials for the Manufacture of Intraocular Lenses: Optic Component

1) Acrylic
   Foldable
   Hydrophilic
   (hydrogels)
Biomaterials for the Manufacture of Intraocular Lenses: Optic Component

1) Acrylic foldable hydrophilic (hydrogels)

Acqua™: “Expandable” IOL
- Proprietary copolymer hydrophilic acrylic (Acryfil CQ) with a bonded UV absorber

- Water content: 73.5%
- Refractive index: 1.409
- Inserted in dry state; hydration/expansion within the capsular bag
Biomaterials for the Manufacture of Intraocular Lenses: Selective Polymerisation

-Vivarte™:

-One-piece phakic anterior chamber lens
-Modification of the Baikoff angle-fixated lens
  (3 points of fixation)
-Foldable (manufactured from a hydrophilic acrylic material, through a selective polymerisation process
-Flexible optic and fixation points; rigid haptics
-Optic diameter: 5.5 mm
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

- **Collamer™**: Hydrophilic collagen polymer (63% hydroxy-ethyl-methyl-acrylate; 0.2% porcine collagen; 3.4% benzofenone for UV absorption)

- Water content: 34%
- Refractive index: 1.45
Biomaterials for the Manufacture of Intraocular Lenses: Optic Component

- Material stated to be “biologically quiet”
- Collagen has an affinity for fibronectin
- Monolayer of fibronectin inhibits deposition of other proteins
- Material not recognized as a foreign body
- Flare, cell deposition and inflammation: minimized

Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

1) Acrylic

*Foldable*

*Hydrophobic*

**Material Specifications:**

<table>
<thead>
<tr>
<th>Material Structure:</th>
<th>Co-polymer 2-phenylethyl acrylate and 2-phenylethyl methacrylate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractive Index:</td>
<td>1.55</td>
</tr>
<tr>
<td>Water Content:</td>
<td>0.3%</td>
</tr>
<tr>
<td>Glass Transition:</td>
<td>11° C +/- 0.2° C</td>
</tr>
<tr>
<td>Water Contact Angle:</td>
<td>72°</td>
</tr>
</tbody>
</table>

*AcrySof®*
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

1) Acrylic
   - Foldable
   - Hydrophobic

Material Specifications:

- **Material Structure:** Terpolymer ethylacrylate, Ethyl methacrylate, and 2,2,2-trifluoroethyl methacrylate.
- **Refractive Index:** 1.47
- **Water Content:** 1.6%*
- **Glass Transition:** 10.6° C +/- 0.2° C
- **Water Contact Angle:** 88°
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

1) Acrylic
   Foldable
   Hydrophobic

HOYA AF-1 (UV)
VA-60BB
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

- SmartIOL™
- Thermodynamic hydrophobic acrylic material, packaged as a solid rod
- Refractive index: 1.47
- Glass transition temperature: 20-30°C
- Body temperature transforms the solid into a gel-like material (30 seconds)
Biomaterials for the Manufacture of Intraocular Lenses: Optic Component

- Rod: 30.0 mm long, 2.0 mm wide
- Biconvex lens: 9.5 mm wide; 2.0-4.0 mm thick
- Flexible, recovers full shape after compression
- Dioptric power and final dimensions can be imprinted before forming the rod
- Restore accommodation? (full size lens; flexible material)
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

Experimental studies: Cadaver eyes
Biomaterials for the Manufacture of Intraocular Lenses: *Optic Component*

2) *Silicone*

![Silicone image]

**Material Specifications:**

**Material Structure:**
- Polydimethyl siloxane (1st generation)
- Polydiphenyl siloxane (2nd generation)

**Refractive Index:**
- 1.41 (1st generation)
- 1.47 (2nd generation)

**Water Content:**
- < 1.0%
Biomaterials for the Manufacture of IOLs

• Glass transition temperature: Above it, the polymer exhibits flexible properties and below it remains rigid

• Foldable acryliks: GTT approximately at room temperature

• Silicones: GTT significantly below room temperature

• Refractive index: Higher with acryliks; lower with silicones
Biomaterials for the Manufacture of Intraocular Lenses: *Surface Modification*

- Surface energy (hydrophilic x hydrophobic): Can be modified; the material will be better adapted to its final use

1) **Surface treatment**
   Create new molecules at the surface; alter surface characteristics (roughness, hardness...)

2) **Coating of the original polymer by adsorption**

3) **Graft of new molecules (with an initial step of surface treatment)**
Biomaterials for the Manufacture of Intraocular Lenses: *UV Absorbers*

Benzofenone

Protection against ultraviolet radiation (300-400 nm)

Benzotriazole
Biomaterials for the Manufacture of Intraocular Lenses: \textit{Haptic Component}
Biomaterials for the Manufacture of Intraocular Lenses: *Haptic Component*

- Fixation of looped IOLs: Pressure on surrounding ocular tissues

- *Loop rigidity*: Resistance of the haptic to external forces

*Loop memory*: Ability to re-expand laterally to the original size and configuration
Biomaterials for the Manufacture of Intraocular Lenses: *Haptic Component*

PMMA


Polyimide

PVDF

Prolene
IOLs with Special Blockers

- SN60AT (Acrysof® Natural)
- Integrated yellow dye, *blue light filtering chromophore*
- Filter invisible UV rays and visible blue rays
- Filtration from 200-550 nm, instead of 200-400 nm
- Transmittance mimics protection provided by precataractous human crystalline lens
- Prolonged exposure to blue light: contributor to age-related macular degeneration
Photochromic IOLs

- SmartYellow™ IOL
- Proprietary hydrophobic acrylic material (Photochromic Matrix)
- Blue-colored PVDF haptics
- Optic changes from colorless to yellow, upon exposure to UV light
- UV-near blue absorption curve similar to the AcrySof® Natural lens when exposed to UV light
- Standard UV absorbing IOL in an indoor environment

Light Adjustable Lens (LAL)

LAL Material Formulation

- Silicone matrix polymer
- Macromer
- Photoinitiator
- Ultraviolet light absorber
Uveal and Capsular Biocompatibility


Protein Adsorption to IOL Surfaces

- First phenomenon after IOL implantation
- Pattern will influence the IOL biocompatibility
- IOL binding more adhesion proteins (fibronectin, laminin and vitronectin) might have better ability to attach to the capsule, which mainly consists of collagen type IV and I
“Sandwich” theory

- Proposed by Dr. Reijo Linnola, MD, PhD (Vaasa, Finland)

- “IOLs having a bioadhesive surface would allow only a monolayer of lens epithelial cells to attach to the capsule and the IOL, preventing further cell proliferation and capsular bag opacification”

Linnola RJ, Werner L, Pandey SK, et al. Adhesion of fibronectin, vitronectin, laminin and collagen type IV to IOL materials in pseudophakic human autopsy eyes

Anterior Capsule Opacification: Interaction with the Biomaterial

- Continuous curvilinear capsulorhhexis (CCC)

  In-the-bag fixation

- IOL optic in contact with the posterior aspect of the anterior capsule
Macroscopic anterior capsule opacification: *Silicone IOLs*

Grades 0 and I

Grades II and III

Grade IV

Microscopic anterior capsule fibrosis: *Silicone IOLs*

Grade 0

Grade I

Grade II

Grade III

Excessive Fibrosis: Capsule Contraction Syndrome, Capsulorrhexis Phimosis

Prolene haptics: Less rigidity
IOL decentration
Prevention of Posterior Capsule Opacification: Squared Edged IOLs
Biomaterials for the Manufacture of IOLs

- IOLs: Acrylies or Silicones
- General classes, *but*
- Each copolymer has different properties
- Surface characteristics can be modified
- IOL design: Can influence outcome of complications
- *Future directions*: IOLs for very small incisions, injectable materials, adjustable materials...