What you're about to see...

- Anatomy and optics of the eye
- 4 Bioengineering case studies:
  - Contact Lenses
  - Artificial Corneas
  - Implanted Lenses
  - Retinal implants
- Conclusion
  - What special challenges and benefits exist for biomaterial engineering for the eye?
The Eye – Front to Back

- Cornea
  - High refractive index
  - Protects eye
- Pupil
- Iris
- Lens / Ciliary Body
- Retina
A flashback to lens physics

\[
\frac{1}{g} - \frac{1}{b} = \frac{1}{f} \quad \frac{g}{b} = \frac{G}{B}
\]
What about refractive index?

- A measure of how slow light travels in a substance compared to a vacuum.
- The cornea's index of refraction is 1.38, so light travels $1/1.38 \approx 0.72$ times as fast as in air.
The Eye – Front to Back

- Cornea
- Pupil
  - Opening of the iris
- Iris
- Lens / Ciliary Body
- Retina
The Eye – Front to Back

- Cornea
- Pupil
- Iris
  - Sphincter to control how much light enters the pupil
- Lens / Ciliary Body
- Retina
The Eye – Front to Back

- Cornea
- Pupil
- Iris
- Lens / Ciliary Body
  - Lens performs fine adjustments to focus
  - Ciliary muscles shape lens
- Retina
The Eye – Front to Back

- Cornea
- Pupil
- Iris
- Lens / Ciliary Body
- Retina
  - Site of light detection
  - Converts light to signals passed down optic nerve
For Completeness...

- **Aqueous Humour**
  - Anterior cavity
  - Metabolic exchange
  - Some refraction

- **Vitreous Humour**
  - Posterior cavity
  - 99% water
  - Structural
Contact Lens

- Concept dates back to 1508 by da Vinci
- Corrective lens on top of cornea
- Commonly used to cure myopia, hyperopia and astigmatism
- Can be fashioned for cosmetic or sight enhancing purposes
Related Diseases

- Myopia
- Hyperopia
- Astigmatism
Related Diseases

- Myopia
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Biocompatibility

• Biocompatibility is the forefront of design consideration

• Three major criteria:
  – Hydrophilic nature
  – Gas permeability
  – Biofilm resistance
Hydrophilic Nature

- Tear layer forms between lens and cornea
- Requires lens to be hydrophilic
- Otherwise lens would not stay in place and stick to the cornea
- Unpleasant
Gas permeability

- Gas moves in (oxygen) and out (carbon dioxide) of cornea
- Part of the gas exchange route
- Must accommodate this permeability
- Otherwise causes discomfort and strain
Biofilm Resistance

- Tears also contain lipids, proteins and other biomaterials
- Lens must not attract these substances
- Otherwise vision is blurred and contact becomes uncomfortable
Types of Contact Lenses

- Hard Contact Lenses
- Rigid Gas Permeable Contact Lenses (RGP)
- Soft Contact Lenses
Hard Contact Lenses

- First type of contact lenses for commercial use
- Initially made entirely of poly (methyl methacrylate) (PMMA) matrix.
- Durable, strong and significantly impermeable
- Not comfortable, could not be worn over 8 hours
RGP Contact Lenses

- A modification of classical hard contacts
- Copolymerization of methyl methacrylate (MMA) with methacryloxypropyl tris(trimethylsiloxy silane) (TRIS)
- PMMA-TRIS for short
- More permeable structure but its hydrophobic
- Methacrylic acid (MAA) to make it less hydrophobic
- Copolymerizing PMMA-TRIS with Fluoromethacrylates increased volume fraction for increased permeability
- Enabled RGPs to be used without removal for up to 7 days

Methacryloxypropyl tris(trimethylsiloxy silane) (TRIS)

1,1,1,3,3,3-Hexafluoroisopropyl methacrylate (HFIM)
Soft Contact Lenses

- Soft Contact lenses:
- Also made of a polymer matrix (hydrogel)
- Very hydrophilic and absorbs water
- As water mass increases lens gains gas permeability at a cost
- First hydrogel made of poly(hydroxyethyl methacrylate) (HEMA) matrix
Soft Contact Lenses

- It is also copolymerized with ethylene dimethacrylate (EDMA) or ethylene glycol monoethacrylate (EGDMA) to increase permeability
Soft Contact Lenses

- Silicon is added to hydrogel (siloxane lens) structures to increase permeability; however, silicon`s hydrophobic nature makes it undesirable
- Siloxane would rise to the surface and create a hydrophobic barrier
- Research has shown that molding these lenses in a polar environment makes them more hydrophilic
Other Uses

• Drug delivery:
  – Nano-particles are embedded within lens polymer matrix
  – Particles slowly defuse through the cornea
The Cornea

- Actually 5 layers: epithelium, Bowman's membrane, stroma, Descemet's membrane, endothelium
- Key features: clarity, refractive properties, chemical properties
Common Problems with the Cornea

- Examples: lattice dystrophy, Fuch's dystrophy, map dot-fingerprint dystrophy, corneal dystrophy, keratoconus, iridocorneal endothelial syndrome, herpes zoster (more commonly known as shingles), ocular herpes, pterygium, Stevens-Johnson syndrome, corneal infections

- Problems requiring transplant include one or more of three conditions: scarring, clouding, deformation
Cornea Transplants

- Two major options:
  - transplant from human source
  - transplant of artificial cornea

- Artificial corneas are more interesting from a material engineering perspective
Artificial Corneas

- Dual-layered hydrogel structure
  - can swell up to 80% water content
- Porous
  - easy integration to surrounding tissue
Hydrogels

- These materials are cross-linked hydrophobic polymers
- This gives them the ability to absorb tremendous amounts of water
- Also, they provide pores for eye cells to occupy for bonding the implant to the eye
Implantable Contact Lens (ICL)

- Implanted into the eye
- Behind the iris and in front of the natural lens
- Reversible alternative to laser surgery
Composition

- Composed of collagen, UV absorbing chromophore and poly-HEMA
- It is hydrophilic and absorbs water for refraction as well as biocompatibility
- Carries a negative ionic charge to repel proteins within the eye (avoid biofilm formation)
- Attracts fibronectin to create a coating matrix to inhibit immune response
Implantable Intraocular Lens (IOL)

- Similar to ICL except natural lens is completely removed and replaced with a collomer lens.
- Used mainly for patients with cataract
Implantable Intraocular Lens (IOL)

- (Surgery procedure video)
A Closer Look at the Retina

- Optic nerve
  - central retinal artery and vein
  - carries visual information to brain

- Fovea
  - contains only cones
  - also, ganglion and bipolar cells are displaced to periphery
How “seeing” Happens

- Light is detected by rods and cones, preprocessed by bipolar and ganglion cells, and transmitted to the brain through the optical nerve.

Fig. 2. Simple diagram of the organization of the retina.
Ailments of the Retina

- Age-related Macular Degeneration
  - leakage of fluid behind fovea
  - foveal cones die, causing vision loss in central field of view
- Glaucoma
- Retinitis Pigmentosa
Ailments of the Retina

- Age-related Macular Degeneration
- Glaucoma
  - eye pressure increases compressing axons of ganglion cells, eventually causing cell death
- Retinitis Pigmentosa
Ailments of the Retina

- Age-related Macular Degeneration
- Glaucoma
- Retinitis Pigmentosa
  - hereditary
  - rod degeneration in all but the fovea
What do all these have in common?

- Breakdown in the photoreceptor -> ganglion/bipolar -> optic nerve pathway
What do all these have in common?

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- Can this behavior be emulated in a digital system?
What do all these have in common?

- Breakdown in the photoreceptor -> ganglion/bipolar -> optic nerve pathway
- Can this behavior be emulated in a digital system?
- Maybe, but putting a chip in your eye isn't so easy
Desirable Implant Characteristics

- flexible, smooth, light-weighted
- bio-compatible with long-term stability
- feasible and safe fixation to retinal surface
Polyimides

nitrogen atoms have a higher electron density than the carbonyl groups and lend it to the acceptor

carbonyl groups suck electron density away from the acceptor unit
donor
polyimides may stack like this allowing the carboxyls of the acceptor on one chain to interact with the nitrogens of the donor on adjacent chains.
Polyimides

- This stacking scheme is what gives polyimides their strength and chemical resilience.
- More importantly it is possible to dope the polyimide substrate with silicon to develop a digital system on it.
- The system is encapsulate in Polydimethylsioxane:
  - well-known biocompatible properties, inert, transparent
  - provides mechanical protection during implantation.
Fixation

- The implant is held on the retina by the restorative force of the polyimide cable.
- A complete vitrectomy is necessary for implantation (more about this later).
Special Issues With the Eye

- Problems
  - Surgically sensitive organ
  - Fluid-maintained structure (pressure sensitive)
  - Non-stationary

- Benefits
  - Low immune response
  - Significant gain
  - Wide range of biomaterials available for sure
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