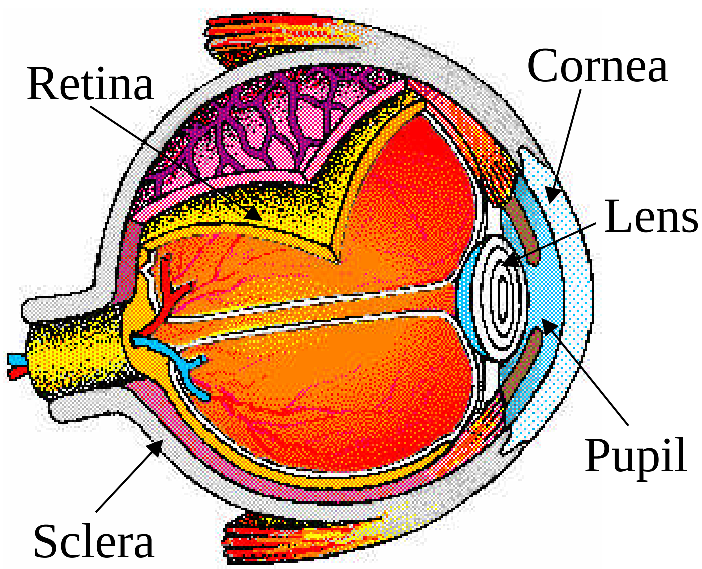
New Materials for Perfect Vision

Julia Kornfield
and Robert Grubbs

Chemistry & Chemical Engineering

Daniel Schwartz

Ophthalmology, UCSF

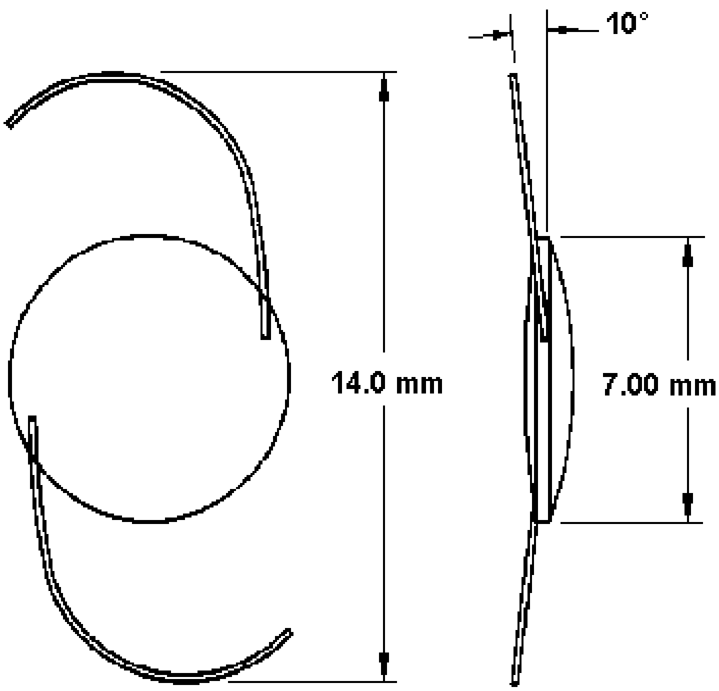


- **Cataract**:
  a cloudy, opaque lens.

Historical Perspective

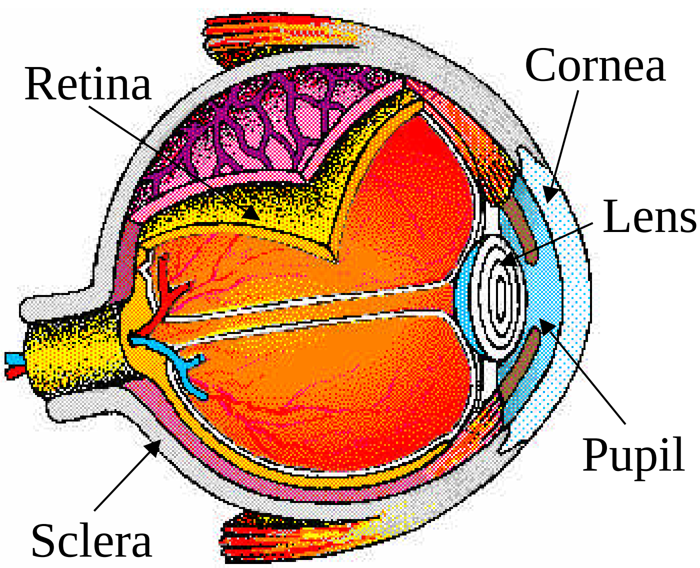
- 5th Century B.C. - “Couching”
- Benito Daza De Valdes (1591-1634) credited with the idea of using an implanted lens.
- 1795 - Dresden ophthalmologist Casaamata attempted the first IOL implant.
- WW II - Bomber Pilots discovered PMMA is biocompatible in the eye
- 1947 - the first successful IOL implant (by English ophthalmologist Harold Ridley)

Current Intraocular Lens (IOLs)



- **Made of either:**
  - –**rigid plastic**
    e.g., Plexiglas™
  - –**flexible elastomer**
    e.g., silicone rubber
- **Power of the IOL is fixed**

The Problem



- **Cataract Treatment**:
  - extraction
  - replacement with an intraocular lens (IOL)
- 3 million implants/yr. US. 14 million/yr. Worldwide
- $1B/yr market in US+Europe+Japan (growing at 3-5%/yr)

Imperfections in wound healing and lens positioning create refractive errors: farsightedness, nearsightedness and astigmatism.

How did Caltech get involved?

Daniel Schwartz

Ophthalmology,
UCSF

Robert Grubbs

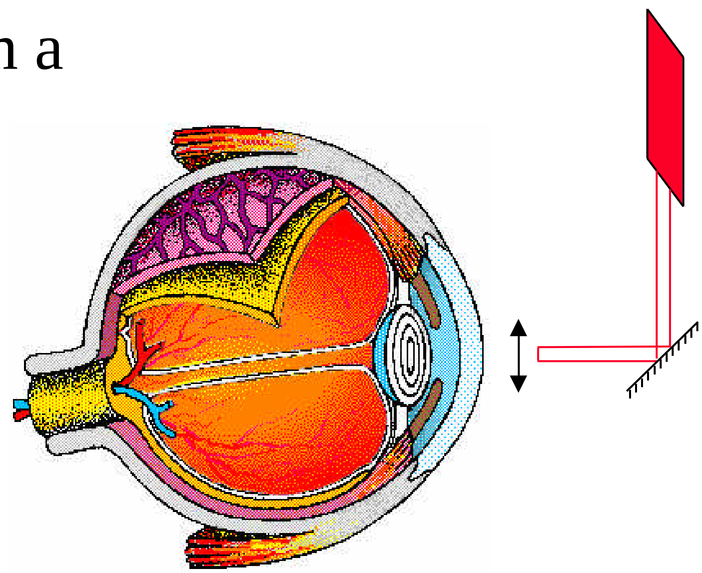
Chemistry,
Caltech

Ideal Features of Adjustable IOL

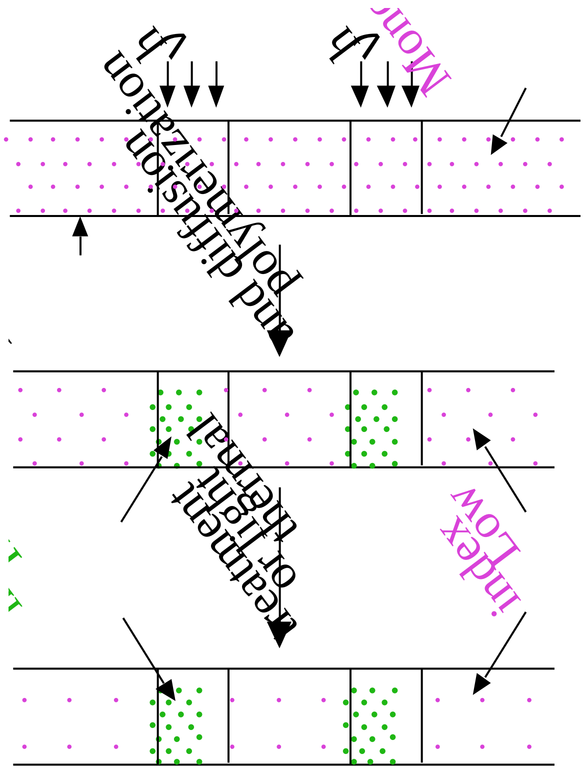
- Precise, Non-invasive Post-op Adjustment
- Correction of Nearsightedness (Myopia), Farsightedness (Hyperopia) & Astigmatism
- Stable Power after Adjustment
- Biocompatible
- Foldable

Idea: Laser Adjustable Lens (LAL)

- Make foldable IOL from a photosensitive material.
- Fine tune IOL power post-operatively by treating with a laser to alter lens shape and refractive index.



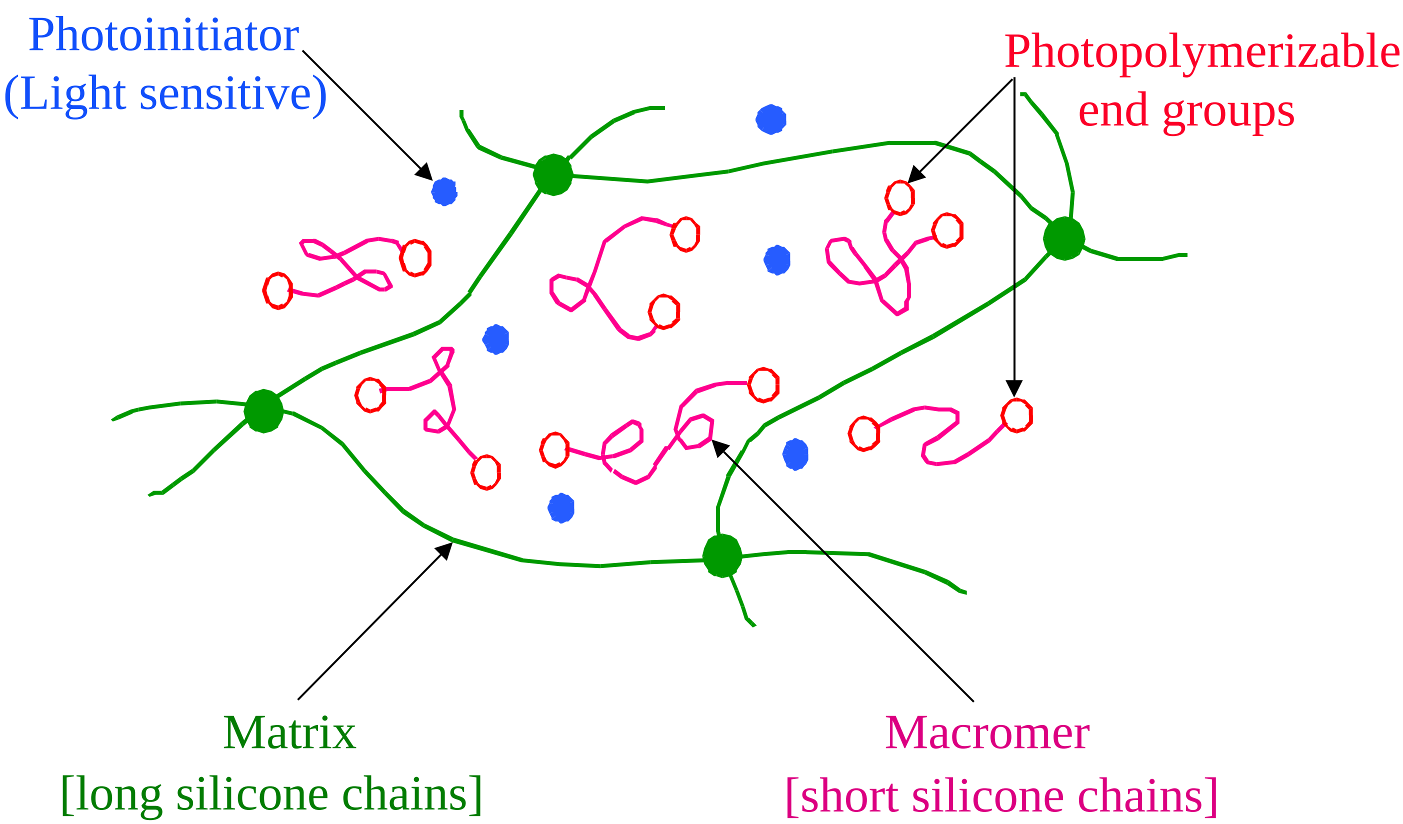
Refractive Index Change by Photopolymerization



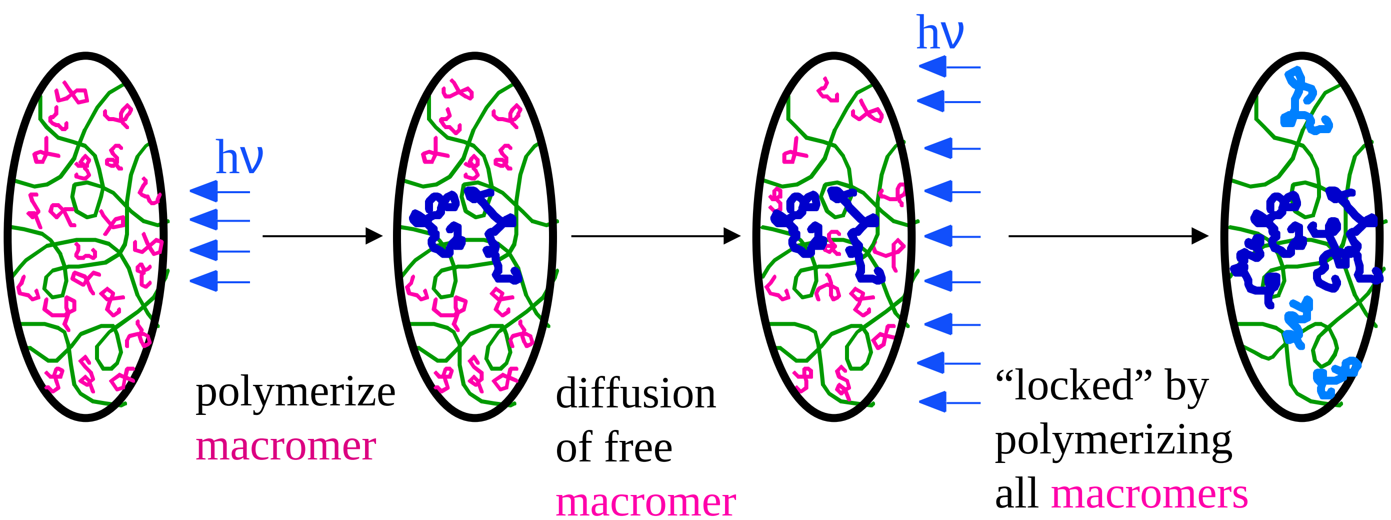
Holography:

- Diffusion of monomer occurs over µm.
- Holograms stored in minutes.
- Would take ~2 yrs. to span an IOL!

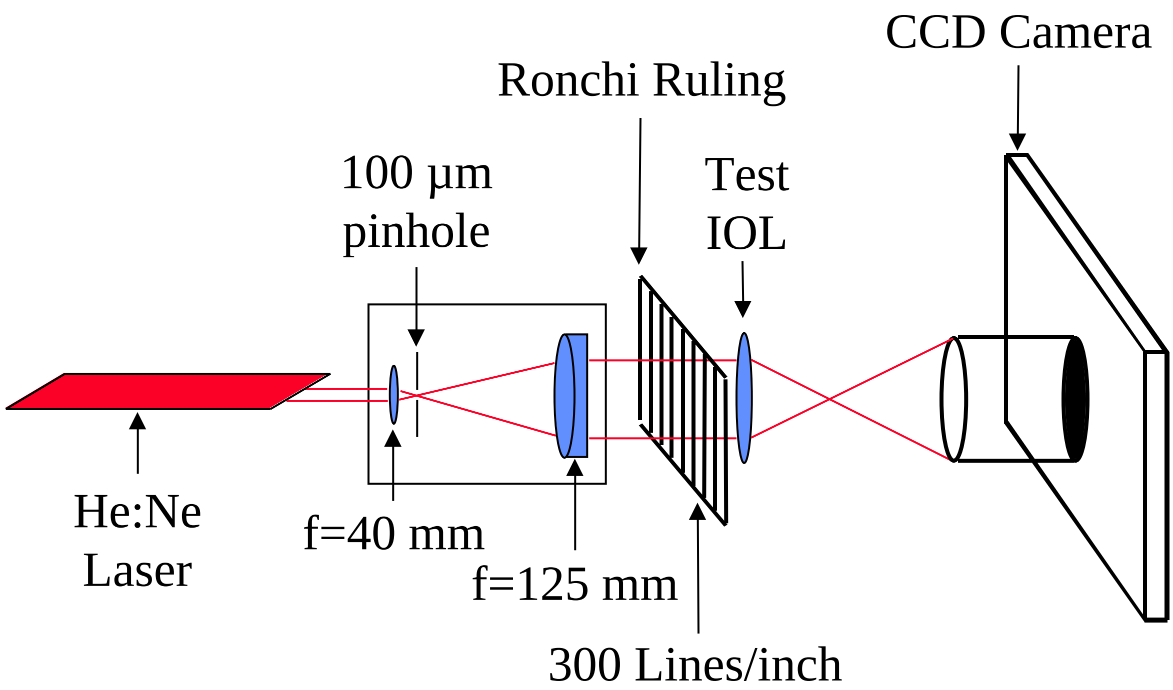
Material Design for LAL



Correction of Farsightedness
by changing refractive index



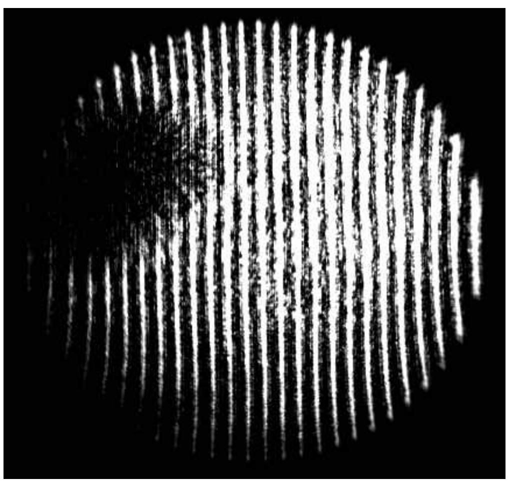
Optical Setup for Lens Characterization



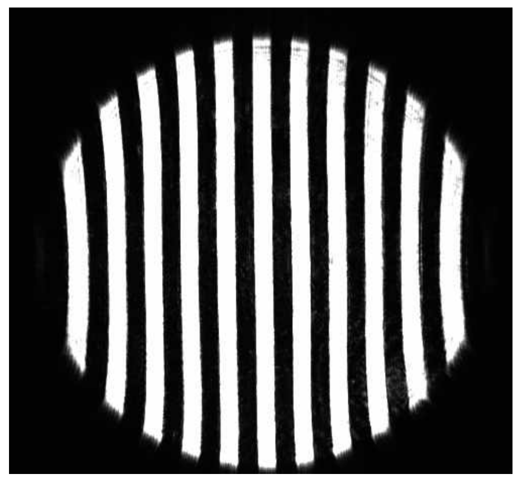
Results Demonstrate:

- Excellent Optical Quality
- Lenses not altered by Ambient Light
- Effective Photolocking
- Controllable Changes in Lens Power
- Stable Power After “Locking”
- Astigmatic Correction

Optical Characterization
Commercial vs. Fabricated IOL



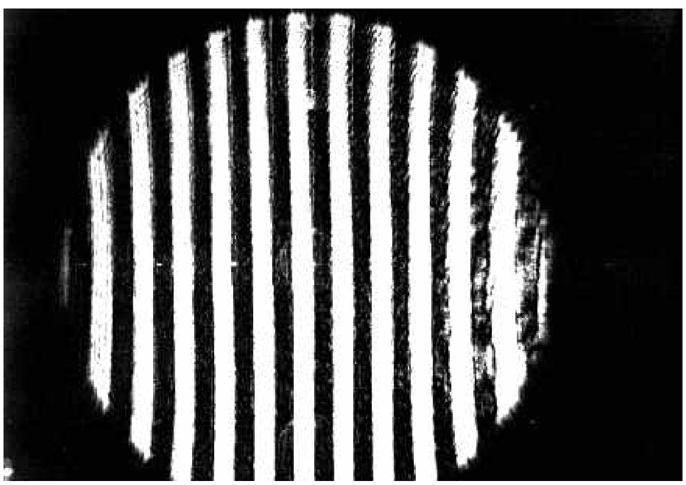
Ronchi Interferogram
Commercial IOL



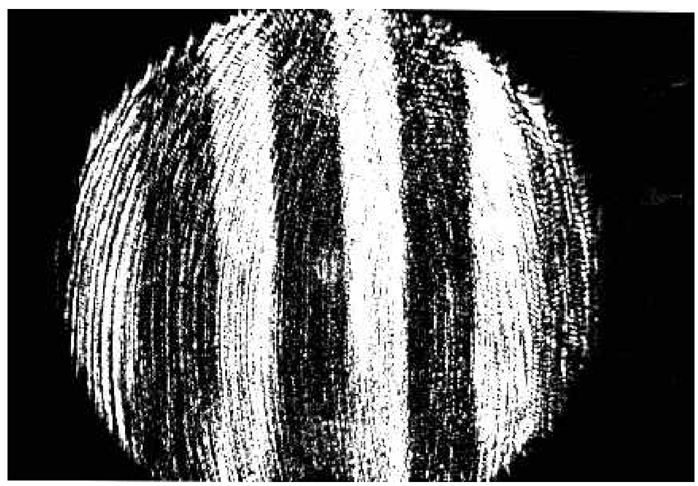
Ronchi Interferogram
Fabricated IOL

➡ The sharp, parallel stripes seen through our lens indicate the **absence of optical aberrations** and the **uniform lens power**.

Demonstration of Power Change



Ronchi Interferogram
Before Irradiation

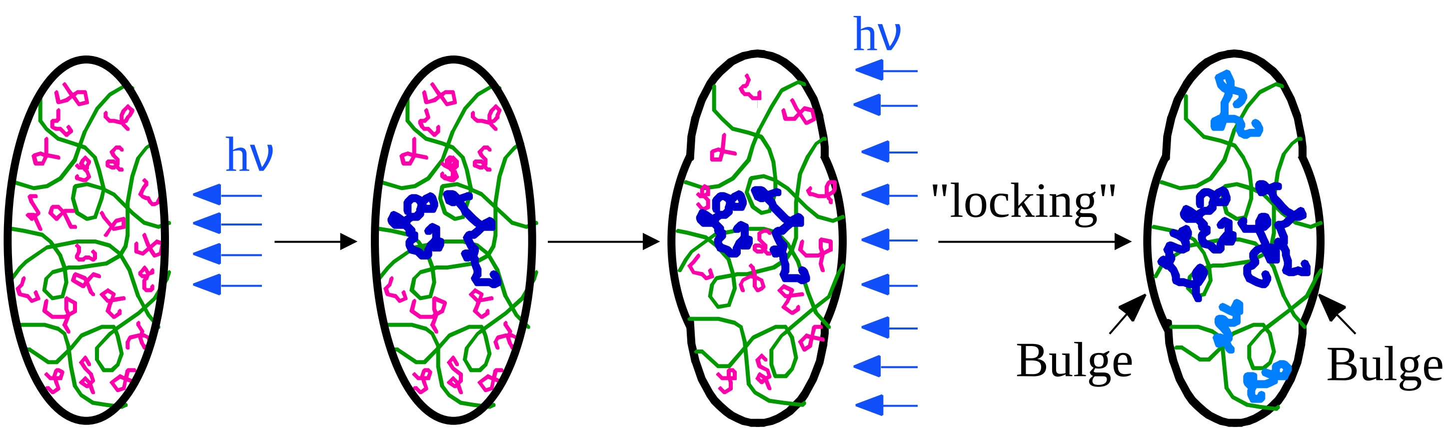


Ronchi Interferogram
After Irradiation

Increase in fringe spacing indicates change in power.

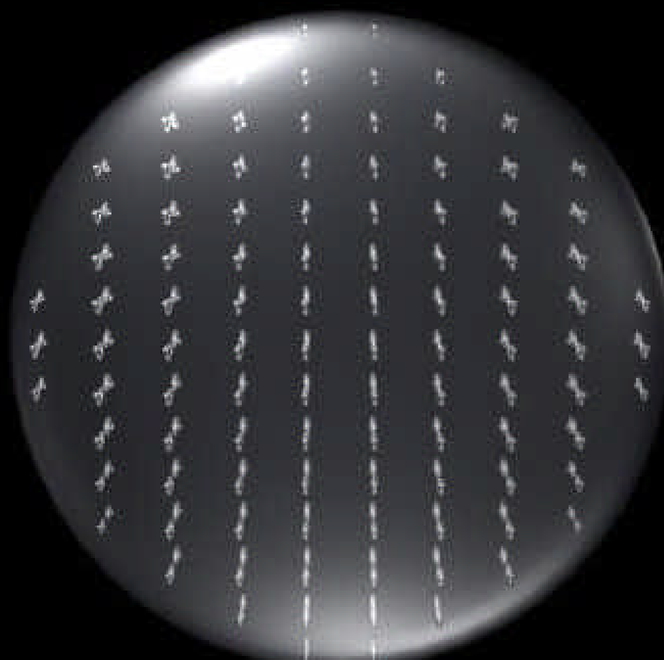
Correction of Farsightedness

by changing shape



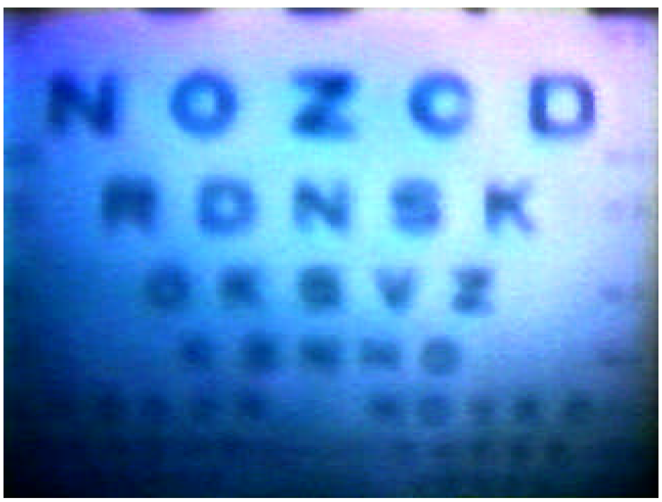
change in surface curvature enhances change in power

HYPEROPIA



Calhoun Vision

Visualizing a 5D Change



Performed by the optics team at Calhoun Vision.

Features of the New Materials

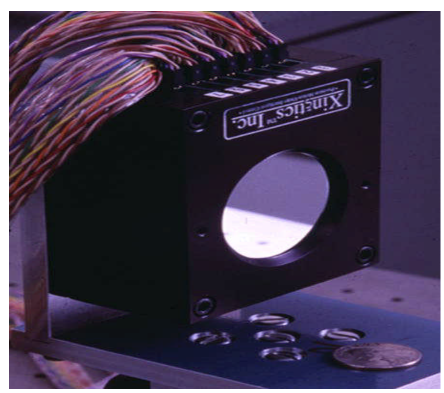
- Silicone photosensitive compositions
  - Lock-in effective
  - No change in ambient light
  - Non-toxic in short term animal studies
- Large enough adjustable range to treat >98% of patients (> 2 Diopters)
- Adjustments can be done with safe exposure to laser light
- Corrects myopia, hyperopia & astigmatism

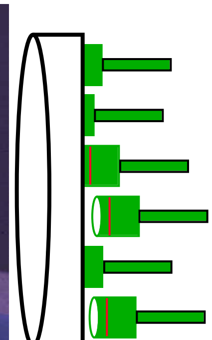
Implications for the Future

- Cataract treatment, and…
- Refractive correction
  - An alternative to surgery on the cornea
- Supernormal vision
  - A practical way to correct any refractive errors (not limited to power and astigmatic corrections)

Adaptive Optics

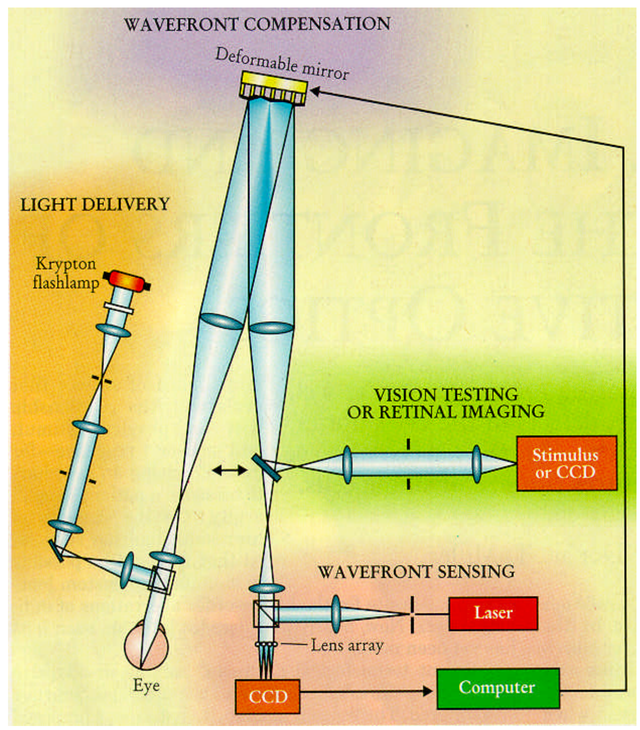
- Corrects Light Distortions in the Medium of Transmission. e.g. Creation of a Road Mirage on a Hot, Sunny Day
- Initially used in Astronomy to Correct for Atmospheric Turbulence in Ground Based Telescopes
- Recently Applied to Improve Microscopy of the Retina





Measuring Aberrations in the Eye

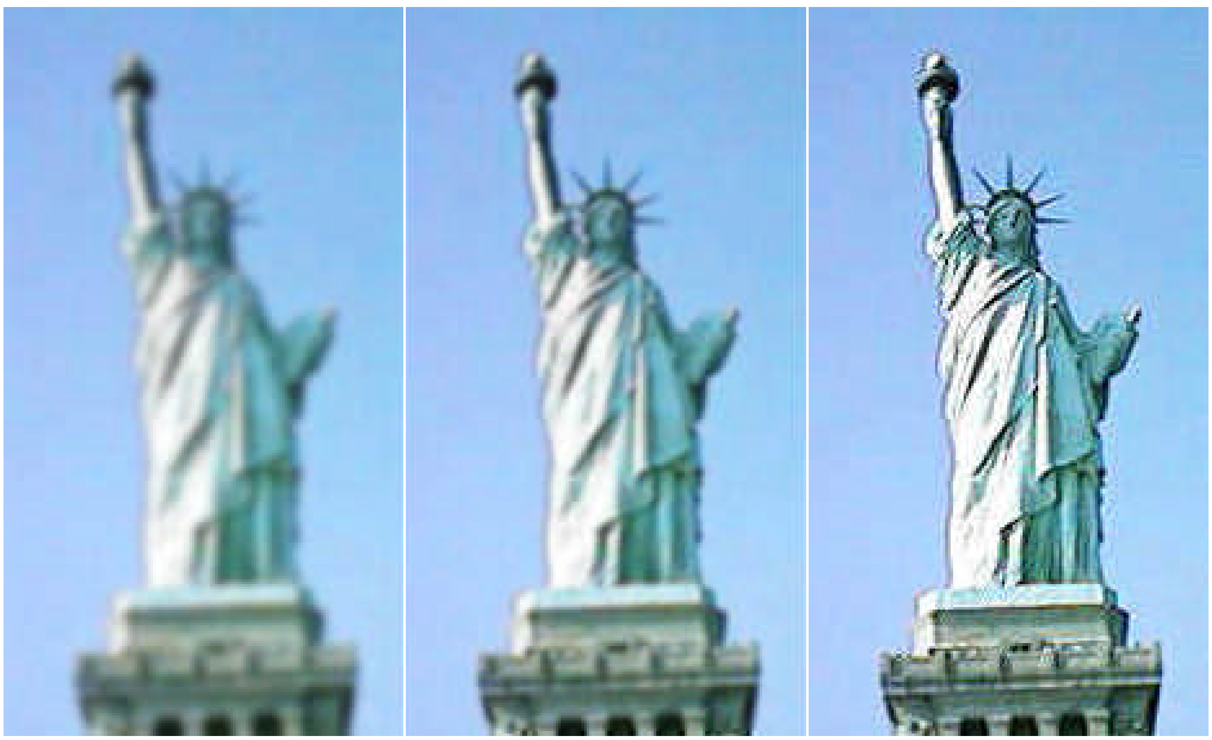
- Pupil is dilated to 6 mm
- Reflected light from retina is analyzed by lenslet array
- Wavefront aberrations effectively nulled by deformable mirror



Donald Miller (Indiana U.)
Physics Today (January 2000)

Comparison of Visual Acuity

(Statue of Liberty viewed at a distance of 3 km)



3 mm diameter pupil normal vision	3 mm diameter pupil corrected optics	8 mm diameter pupil corrected optics

Adapted fromDonald Miller “Supernormal Vision”, *Physics Today* (January 2000).

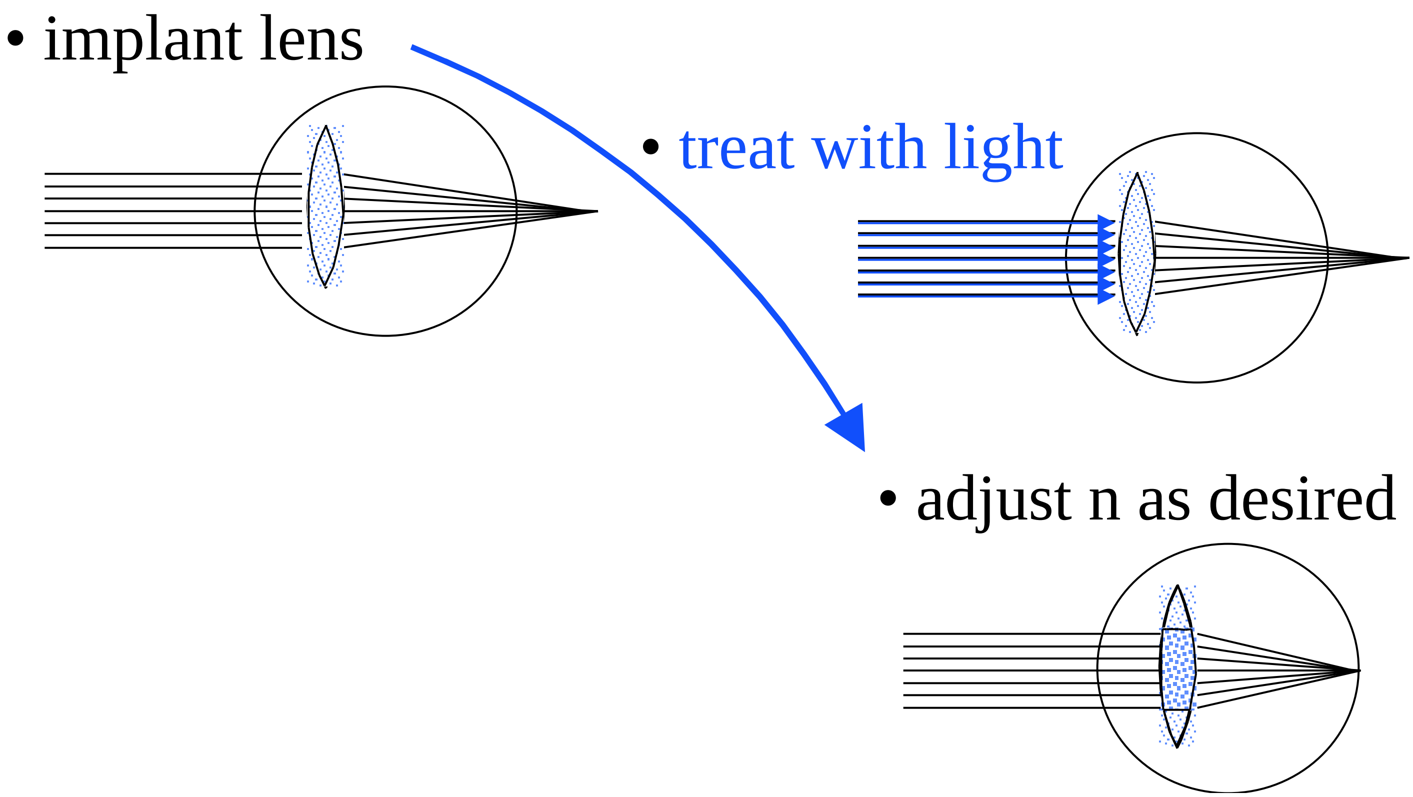
Acknowledgements

Jagdish
Jethmalani

Chris
Sandstedt

- “That Man May See” Foundation
- Chartrand Foundation
- Calhoun Vision

Initial Plan: Change Lens Power by Changing Refractive Index



Key Ingredients for LAL

- Foldable
- Rapid diffusion of free molecules
- Biocompatible:
  - Use a polymer that works well in the eye
  - Use free molecules that won't come out

Try **silicone**!

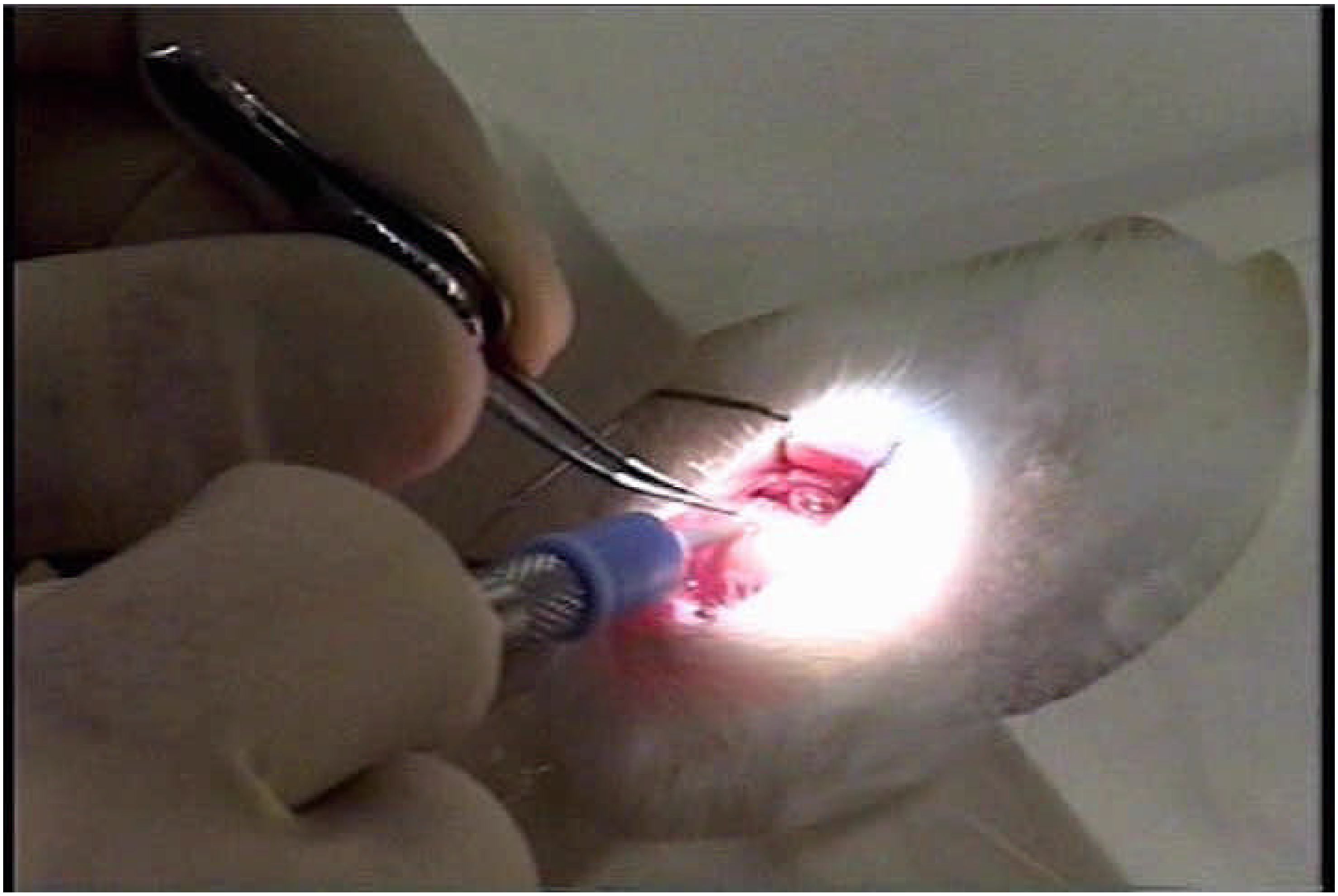
Preliminary Animal Study by Calhoun Vision

- Lens replacement was performed on rabbits using LAL
- A prototype device to enable surgeons to apply the UV light to adjust the LAL was used to treat the implanted lenses
- Quantitative changes in lens power were reproducibly achieved

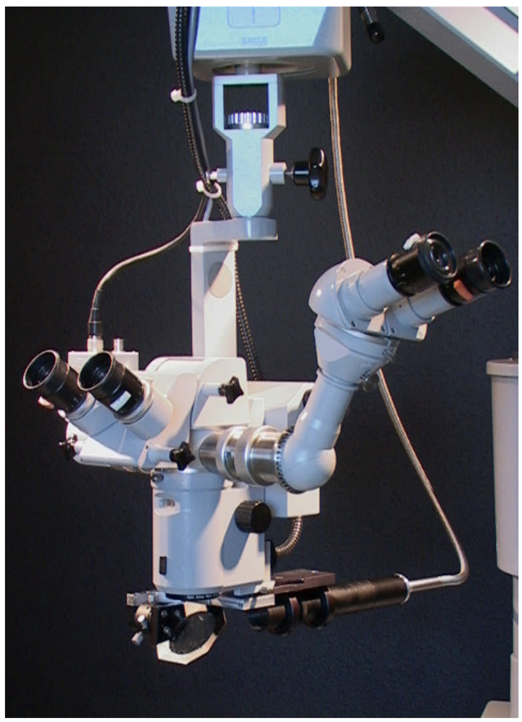
Procedure demonstrated in Rabbits

- Remove the natural lens (phakoemulsification)
- Roll-up and implant the LAL
- Close the wound and allow the eye to heal
- Treat with UV light (dose calculated to produce +0.7D change)
- Remove the lens later for characterization

Animal study conducted by Calhoun Vision.

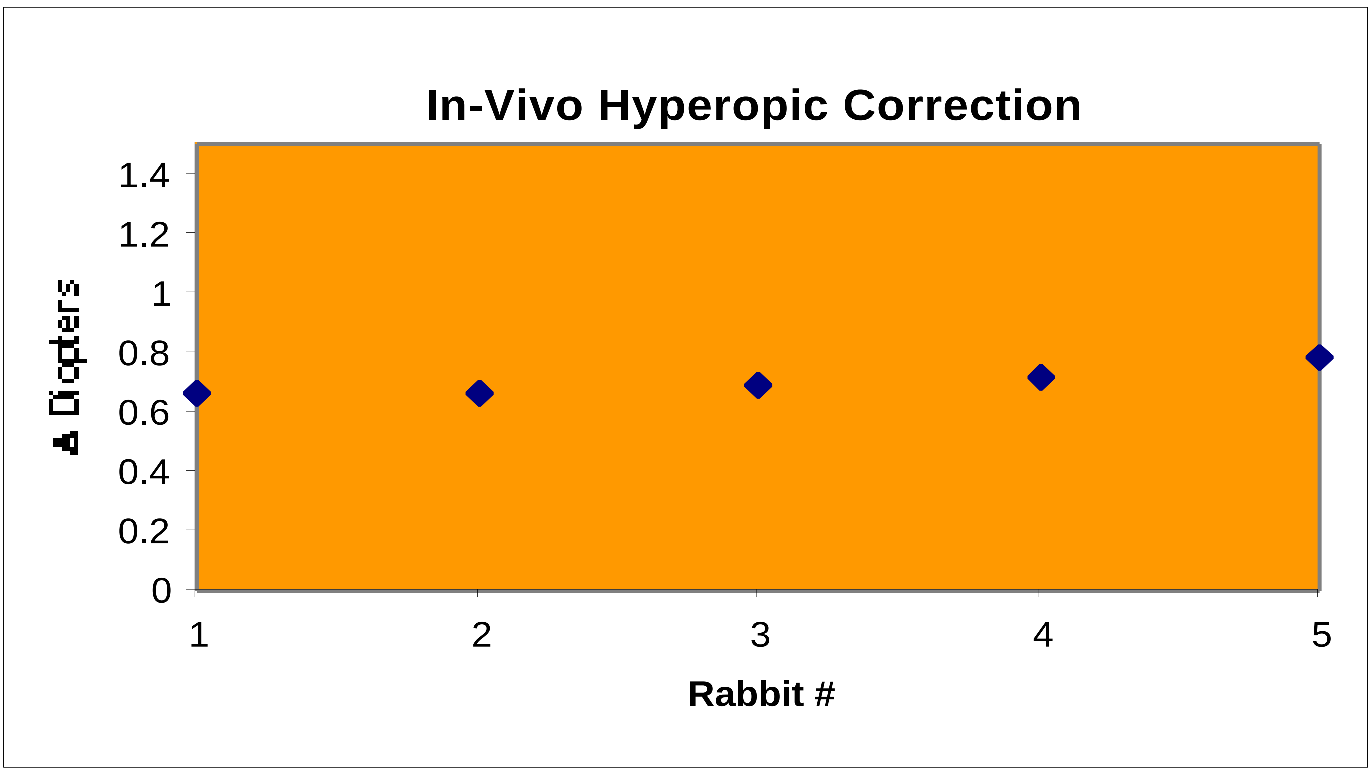


Light Delivery System

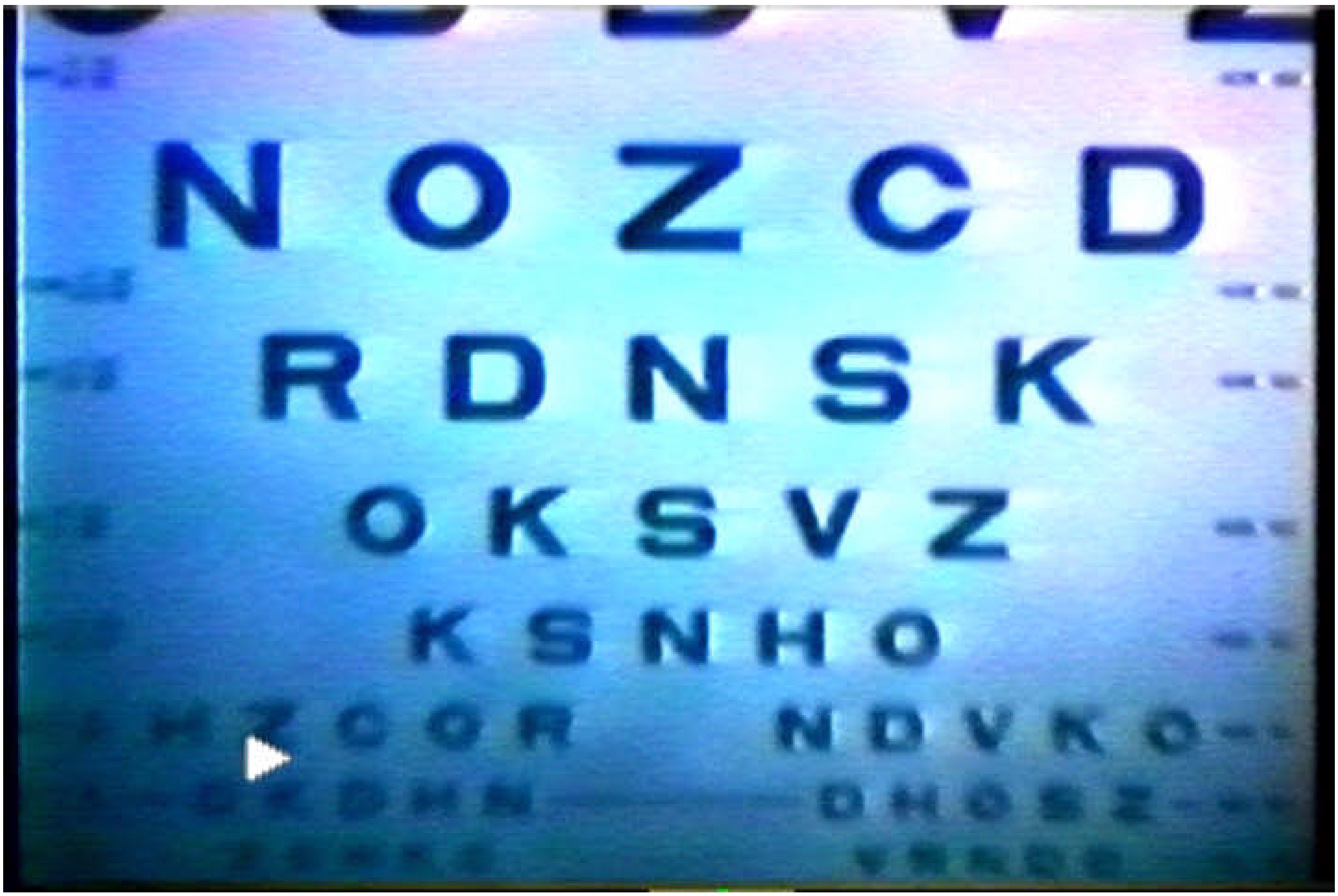


Surgical Microscope Based System developed by Calhoun Vision.

Observed Adjustment in Rabbits

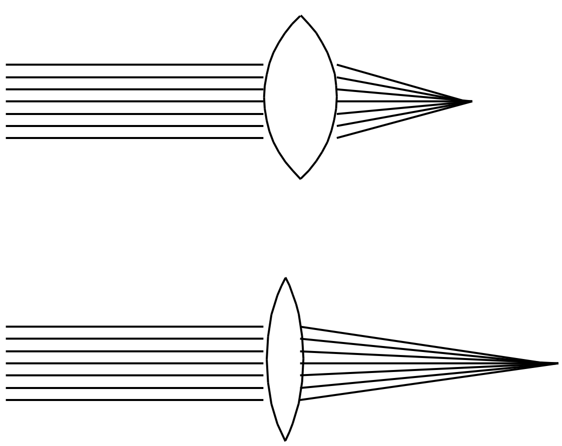


Animal study conducted by Calhoun Vision.

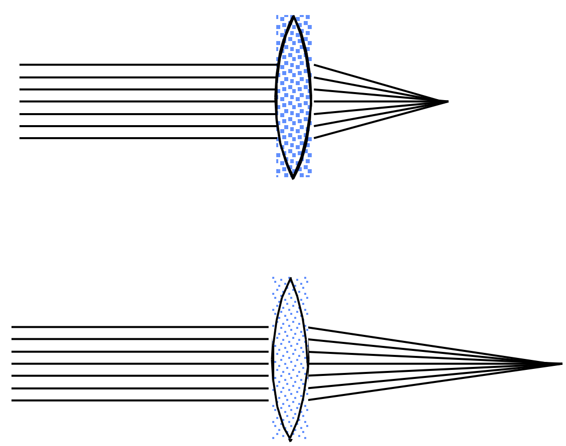

N O Z C D
R D N S K
O K S V Z
K S N H O
N D V K O

Lens Power depends on Shape and Refractive Index

- shape



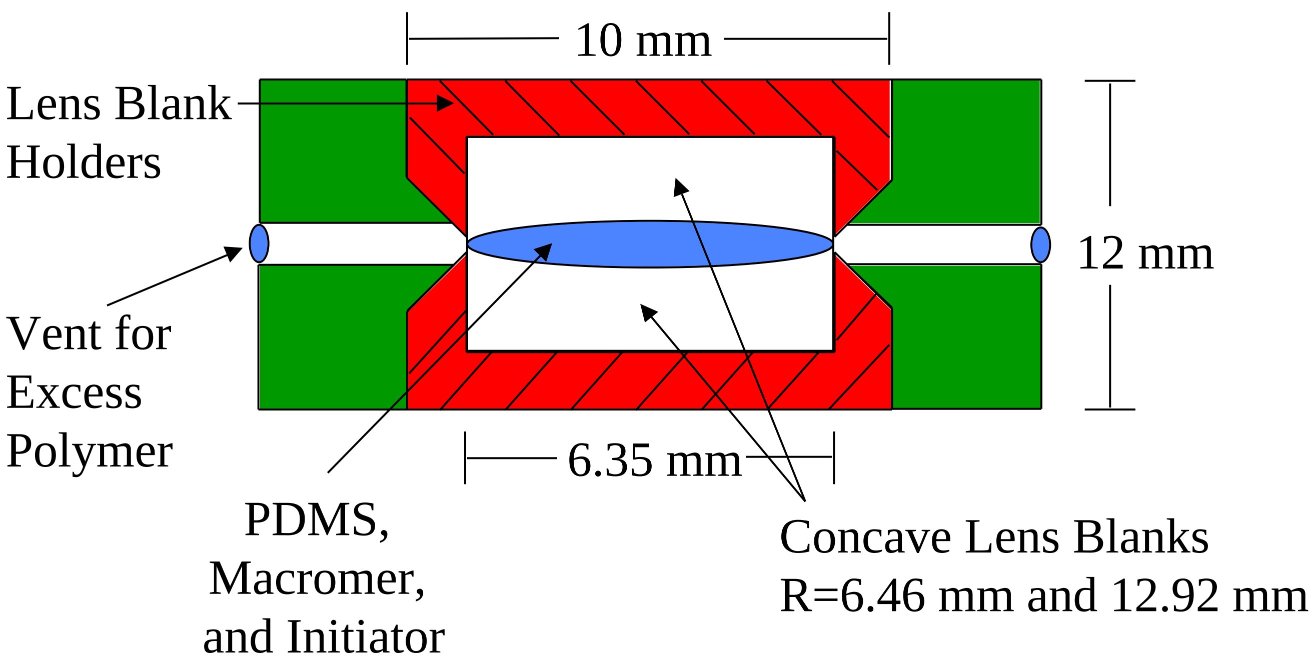
- refractive index (n)



The Quest for Polymers for Perfect Vision

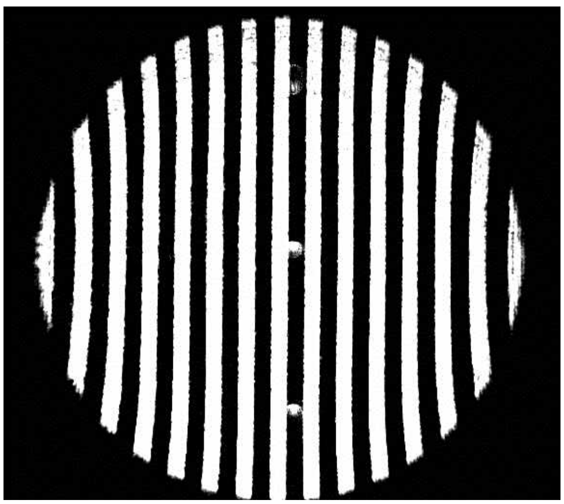
- Approach: Photochemistry and Polymer Physics
- Lens Performance
- On the Way to Clinical Trials

Lens Molds

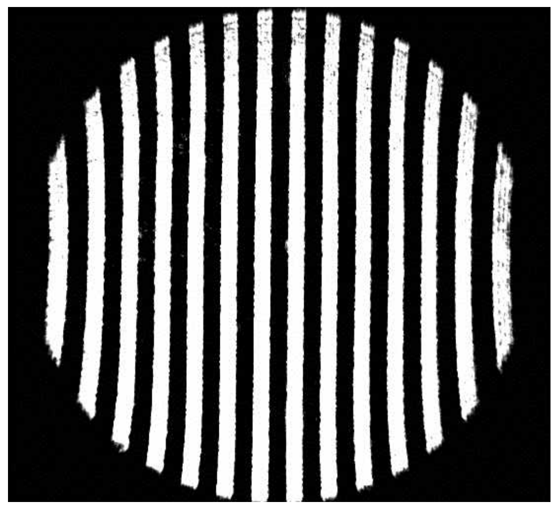


10 mm
Lens Blank
Holders
12 mm
Vent for
Excess
Polymer
6.35 mm
PDMS,
Macromer,
and Initiator
Concave Lens Blanks
R=6.46 mm and 12.92 mm

Does “Locking” Change IOL Power?



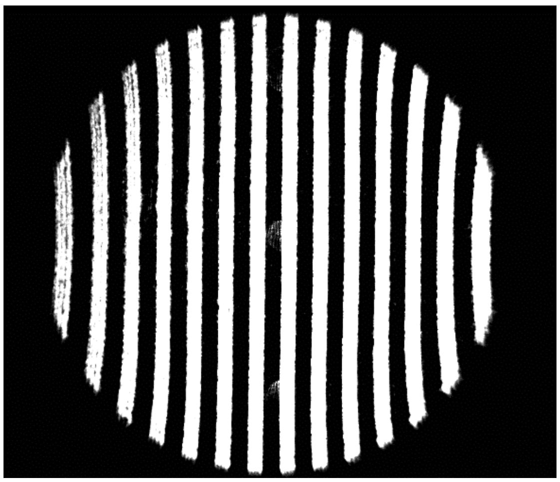
Ronchi interferogram of unirradiated IOL



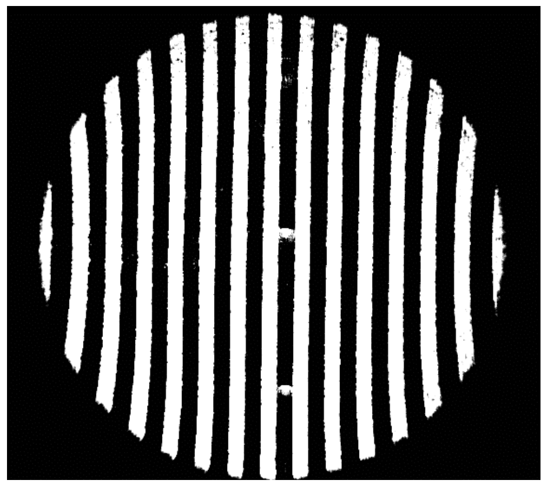
Ronchi interferogram of irradiated and “locked” IOL

No change in fringe spacing indicates no change in lens power.

No Effect of Ambient Light on LAL

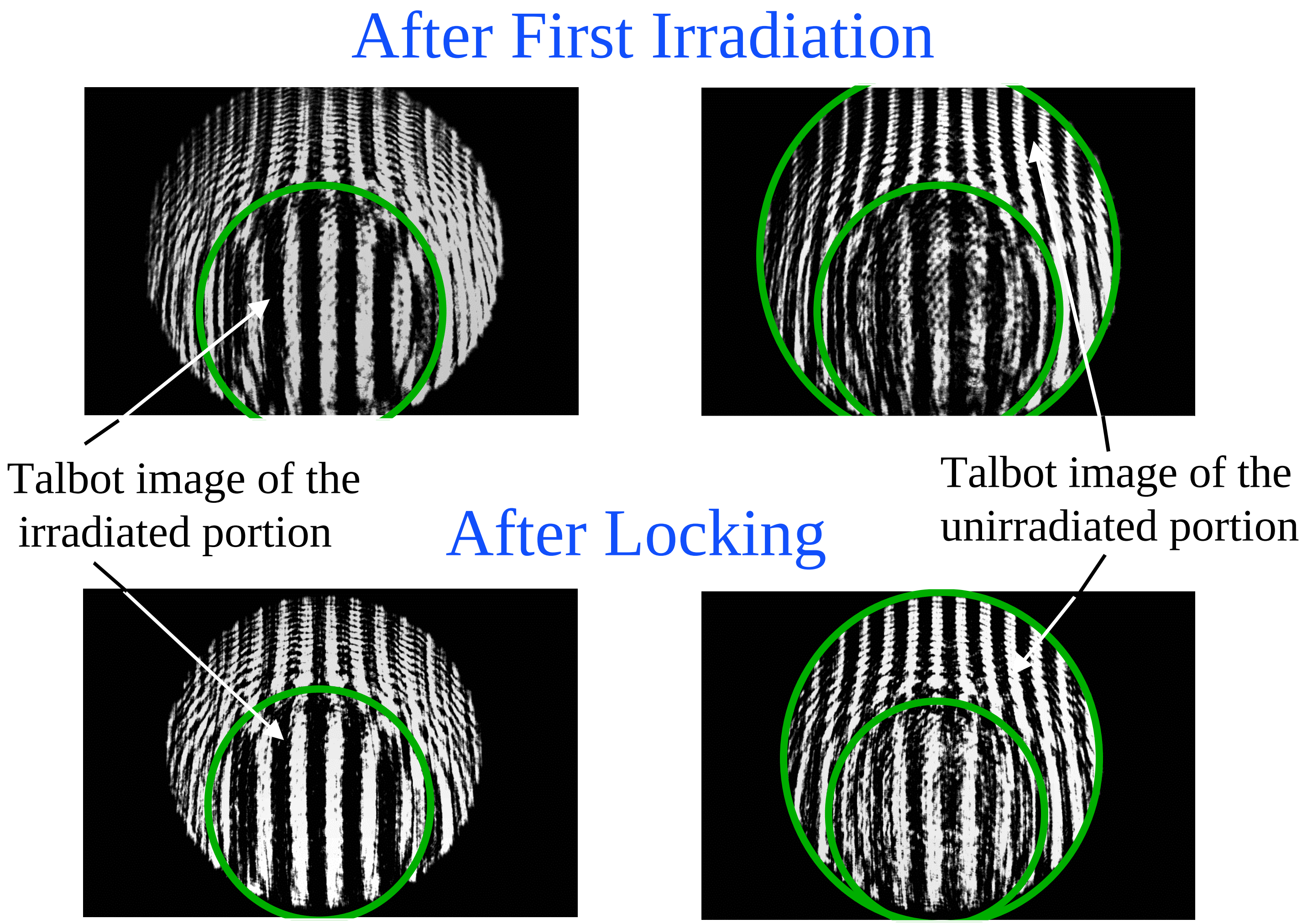


Ronchigram for lens immediately after removal from mold

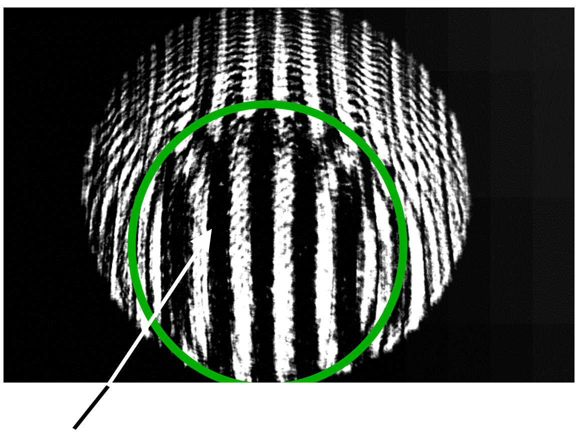


Ronchigram for lens after 96 hours of exposure to room light

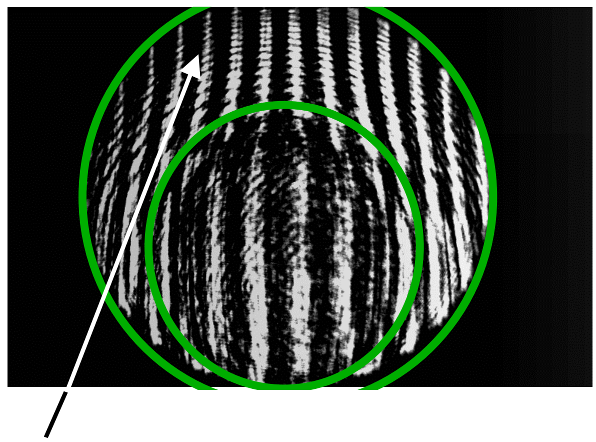
Room light will not induce unwanted photopolymerization.


After First Irradiation
Talbot image of the irradiated portion
After Locking
Talbot image of the unirradiated portion

Is Photolocking Complete?



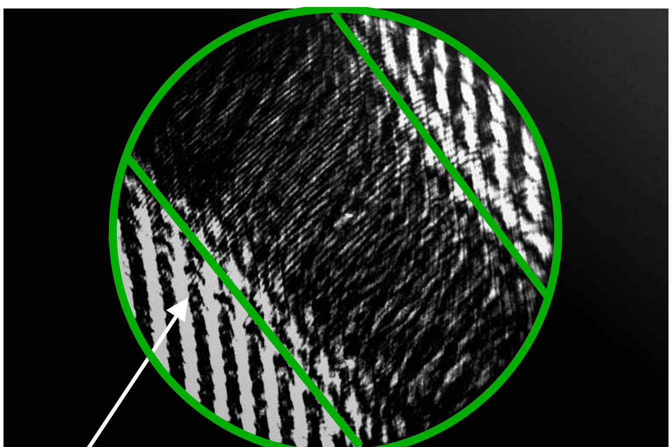
Talbot image of the irradiated portion of the lens.

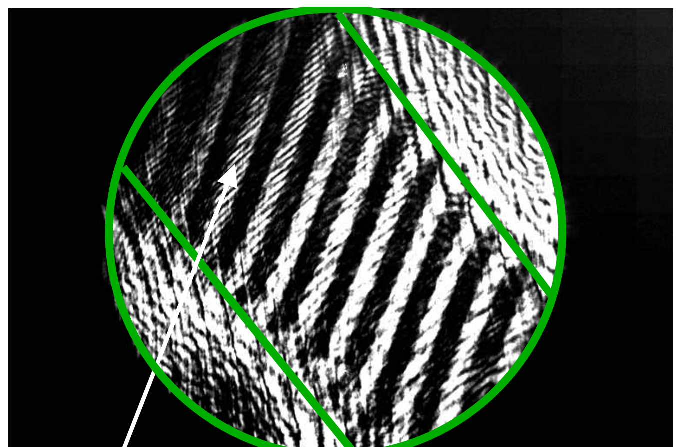


Talbot image of the unirradiated portion of the lens.

==> Photolocking successful in preventing further power changes in the lenses while also maintaining optical clarity.

Astigmatic Correction





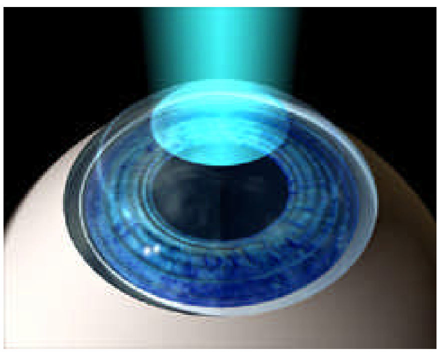
Talbot Image of the Unirradiated Portion of the Lens.

Talbot Image of the Irradiated Portion of the Lens.

➡ Control of the azimuth and magnitude of the astigmatic correction.

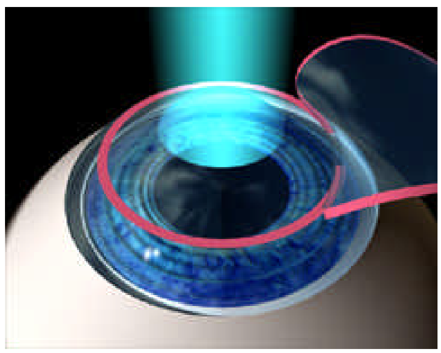
PRK, LASIK and Intacs

Photorefractive Keratectomy



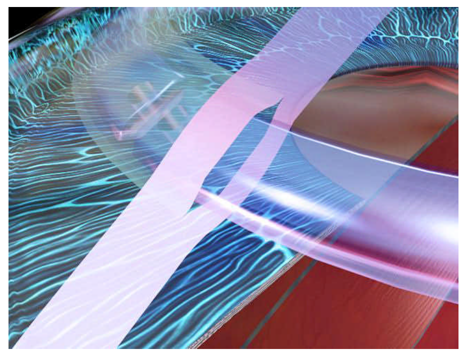
PRK uses a laser to remove corneal tissue and thereby flatten the cornea for nearsightedness or steepen it for farsightedness. The laser operates on the surface of the cornea.

Laser In-Situ Keratomileusis



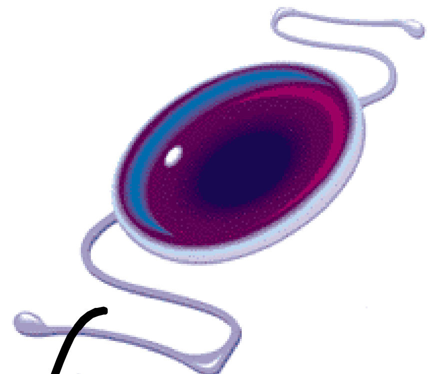
LASIK uses a microkeratome to create a circular flap of corneal tissue. An excimer laser removes tissue from the exposed cornea. The corneal flap is repositioned afterward.

Intacs



Implantation of rings inside the cornea to flatten it for correction of nearsightedness.

Phakic IOLs



- Refractive correction
- Implanted behind cornea and in front of the natural lens