CMRR Center for Magnetic Recording Research

Conference on
Information Storage and Processing Systems

August 28-29, 2023

UC San Diego
JACOBS SCHOOL OF ENGINEERING

The Use of an Artificial Cornea for Validation of a Novel Intraocular Pressure Measurement Device

Avinash Laha[1,2], Aravind Srinath[1,2], Frank E. Talke[1,2]

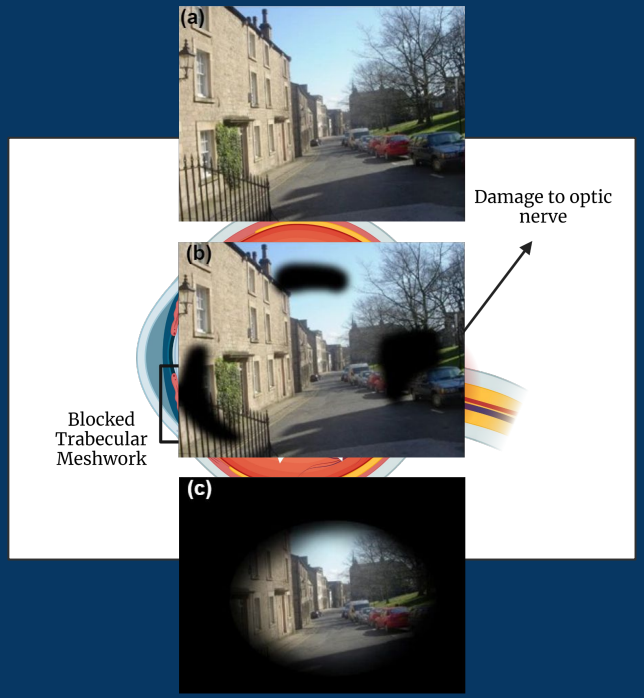
[1]University of California, San Diego, CA, USA
[2]Center for Memory and Recording Research, San Diego, CA, USA

Outline

- Introduction to Glaucoma Screening
- State of the Art
- Design solution - Handheld 3-in-1 Device
  - Structural Description
  - Prototype Implementation
- Artificial Cornea Models
  - Design Considerations
  - Methods of Fabrication
  - Simulation of Intraocular Pressure
- Performance Testing with Tonometers
- Summary

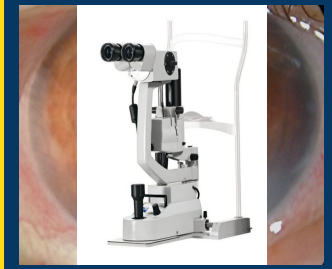
Introduction to Glaucoma

- Primary cause of irreversible blindness in the world
- Risk Factors
  - Old age, physical + mental health, genetics
  - Elevated intraocular pressure (IOP) causing pressure on optic nerve
- Causes slow deterioration of vision field
- Often not self-diagnosed and surgical cure at later stages proven ineffective



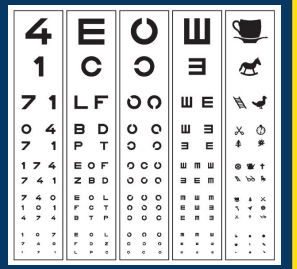
Comprehensive Screening

Standard Eye Examinations



Anterior Segment

Intraocular Pressure



Visual Acuity

Fundus

- Comprehensive exams for glaucoma can be time consuming and costly
  - Patients may not be able to travel or perform routine tests regularly
  - Post-surgery examinations required to screen for complications
- Need to develop easy-to-use, self-examining devices for glaucoma screening

Proposed Solution

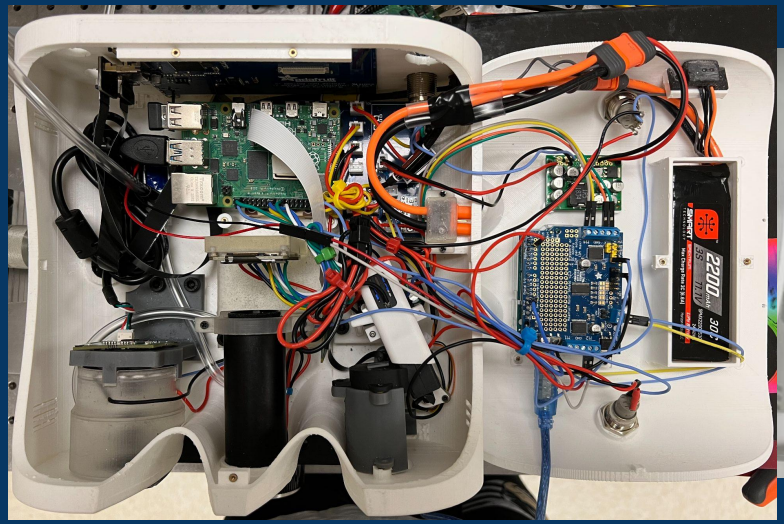
Design and **Rapid Prototyping** of a portable ophthalmic device that combines:

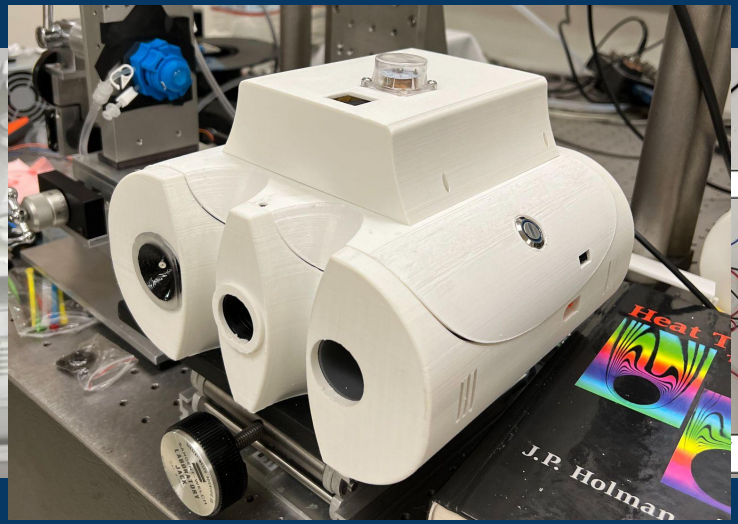
- **Slit-lamp** examination
- **Visual acuity** screener
- Non-contact **tonometer**

⟶ *The device should be easy-to-use, internet-enabled and allow self-examination*

First Prototype Implementation

Layout | CAD Design | 3D Printing | Soldering & Wiring | Assembly & Testing





Tonometry and Calibration Standards

- IOP fluctuation is the biggest risk factor for glaucoma and related diseases
  - Tonometers essential for early detection
- However, high variability between different tonometers
  - Some use adjusted “bIOP” calculations to account for cornea thickness, curvature, etc.
- Calibration needed to ensure reliable IOP readings at varying eye pressures
- Controlled using manometer chamber filled with water/other fluid
  - Excised cornea samples (ex-vivo)
  - Cannulated samples (in-vivo)
  - Artificial Cornea Models

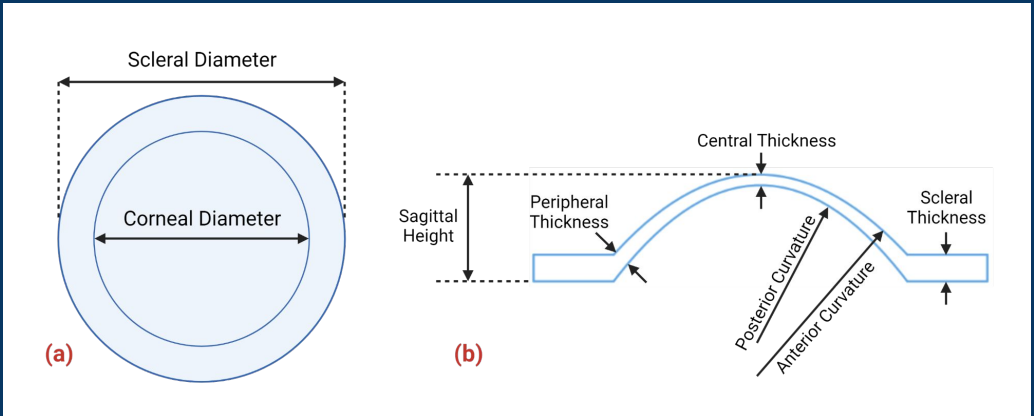
Excised Cornea

Artificial Cornea

Cannulated Cornea

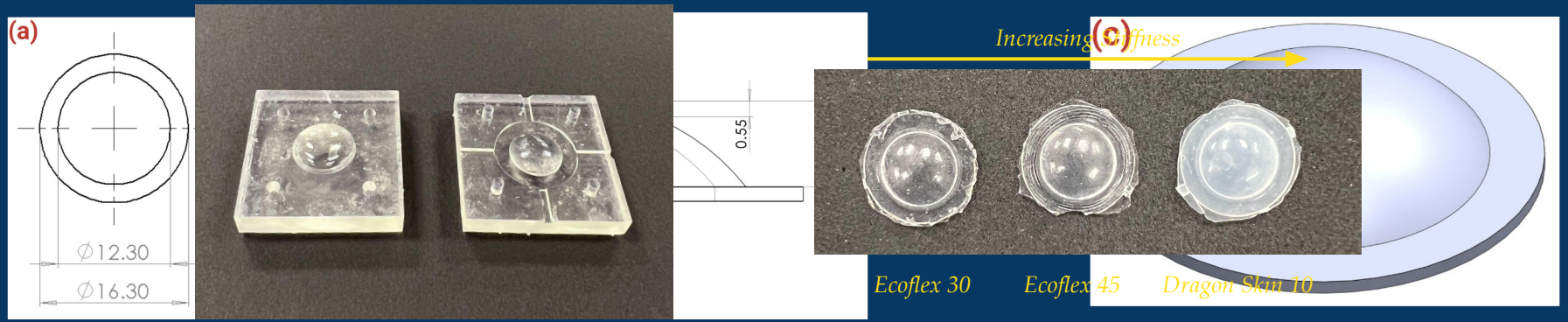
Artificial Cornea Design Considerations

- Goal: To validate working principle and calibrate the tonometer system
- Important to capture:
  - Geometrical dimensions of human cornea
    - Variance in some can create inaccurate tonometer readings
  - Mechanical behavior similar to human cornea in response to elevated IOP



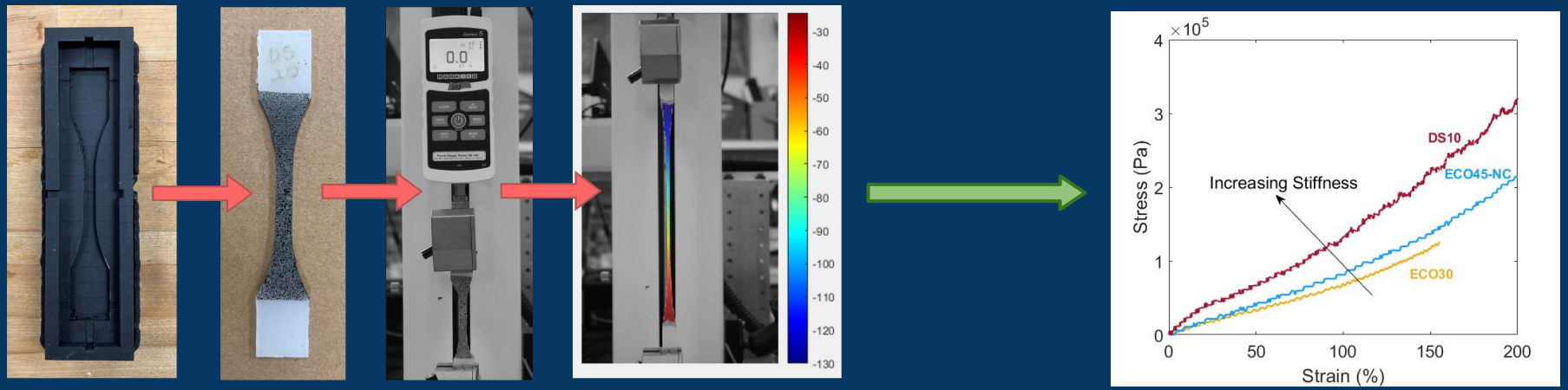
Methods of Fabrication

- CAD Model designed using human corneal dimensions in literature
- Silicone Molding Process
  - 3D printed custom two-part molds developed with this geometry
  - Three silicone materials chosen with documented Young's moduli within human corneal range
  - Silicone mixed and cured for 24 hrs @ room temperature to obtain samples



Materials Selection - Tensile Testing

- Coupon tensile testing performed to confirm uniaxial test data and Young's modulus values
- Coupons molded using 3D printed mold (ASTM D638-14)
- Uniaxial testing and DIC performed on all chosen materials



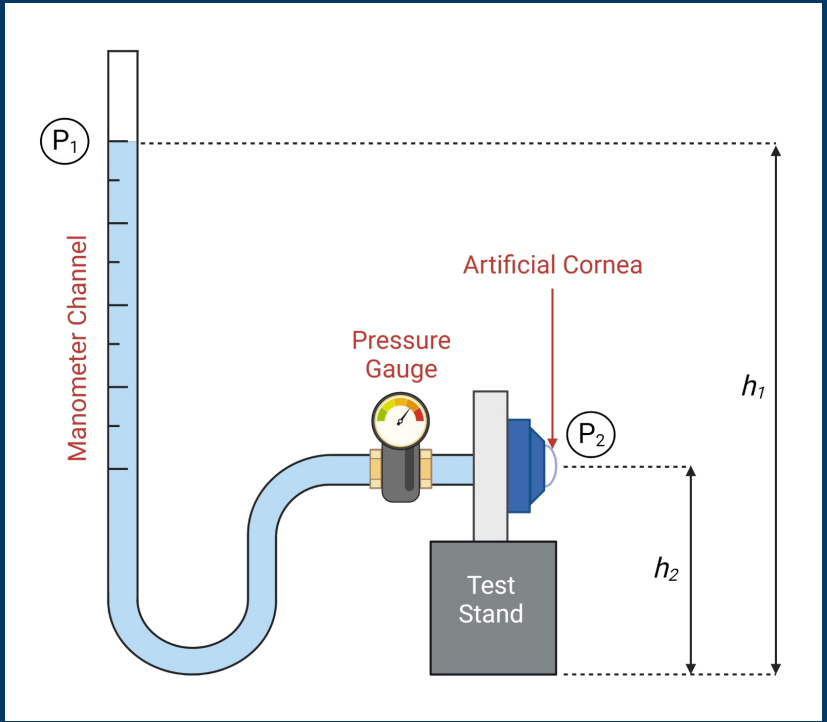
Simulation of Intraocular Pressure

- Silicone corneas clamped and connected to a manometer water column
- Height can be adjusted to simulate varying range of IOP

$$P_2 = \rho g(h_2 - h_1) = \rho g \Delta h$$

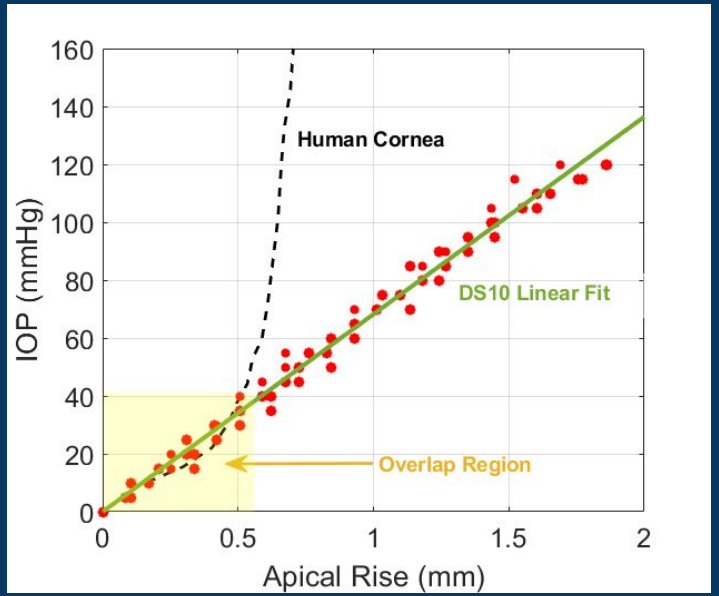
Table 3.2. Calibration table for manometer channel in the phantom eye setup.

Manometer Pressure (mmHg)	0	10	20	30	40
Column Height, Δh (cm)	0	13.60	27.21	40.81	54.42



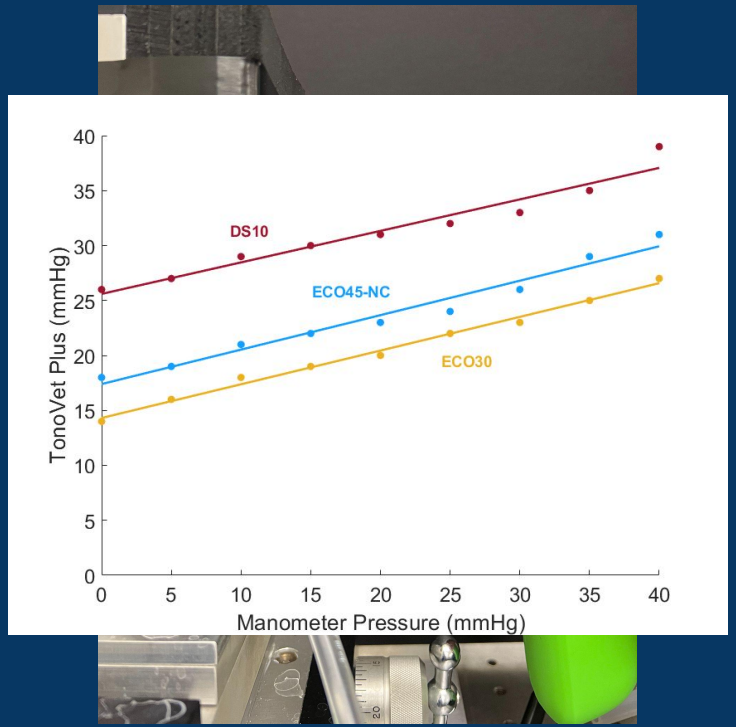
Materials Characterization - Inflation Tests

- Corneal response under elevation of IOP can be studied to reveal similarities and differences with human cornea
- Corneal setup tested between 0-120 mmHg
- Results
  - DS10 linear up to 120 mmHg
  - ECO45-NC linear up to 55 mmHg
  - ECO30 nonlinear after 25 mmHg
- DS10 closest to human cornea apical displacement
  - Up to 40 mmHg



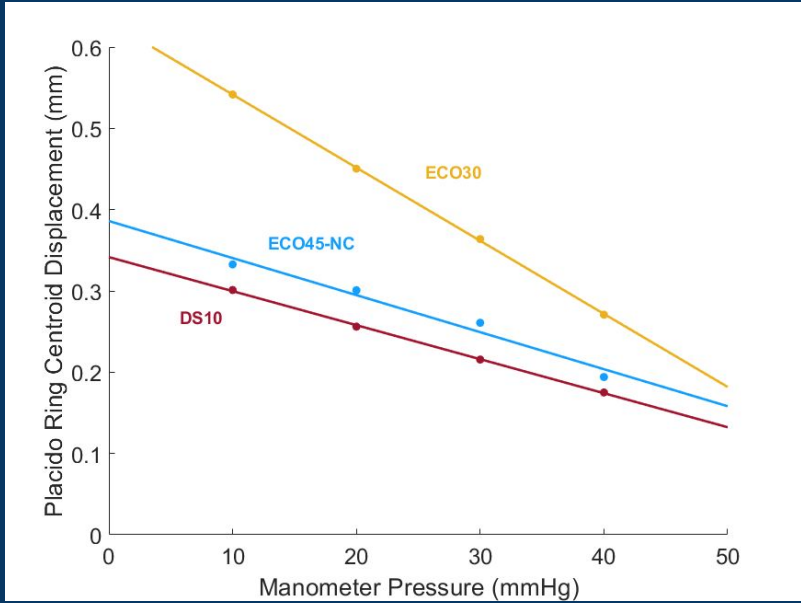
Performance Testing - Commercial Tonometer

- iCare TonoVet Plus Rebound Tonometer
  - Measures speed of miniature probe rebounding off the corneal surface to calculate IOP
- Tested on rabbit setting → similar corneal thickness to humans
- Testing to validate all developed cornea samples at different IOP
- Results
  - Linear increase with increasing IOP
  - Higher stiffness → Higher reading range



Performance Testing - 3-in-1 Device

- Air jet pulse mechanically applanates the cornea while recording movement of projected placido rings
- MATLAB filtering algorithms employed to analyze change in ring centroid displacement
- Results
  - Inverse relationship between IOP and placido ring deformation
  - Stiffer samples → lower range of deformation



Summary

- Successful rapid prototyping of a portable ophthalmic device that allows self-examination of the eye
- Artificial cornea with tunable geometry and material properties
- Pre-clinical validation shown by linear relationship with changing IOP and prospect of calibration

Future Work:

- Exploration of composite materials to imitate strain-stiffening in corneas
- Follow-up testing with accurate human tonometers and excised corneas
- Making the device more user-friendly for higher patient variance
- Planning first clinical tests and further research development

Thank You!