Modelling Goldmann applanation tonometry to improve accuracy of glaucoma screening

Emerging Researcher Symposium

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our future through science

Background

- Glaucoma is the second leading cause of blindness, after cataracts.
- It is the primary cause of irreversible blindness.

Quigley, H.A. & Broman, A.T., 2006. The number of people with glaucoma worldwide in 2010 and 2020. British Journal of Ophthalmology, 90(3), pp.262–267.

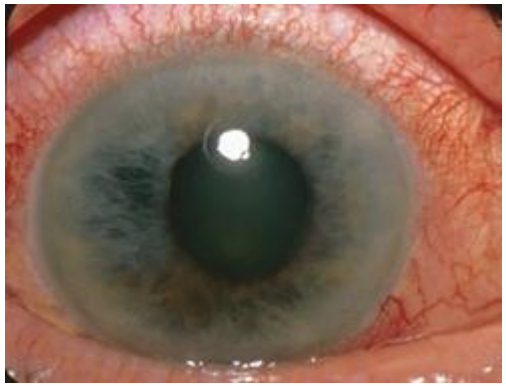
Background

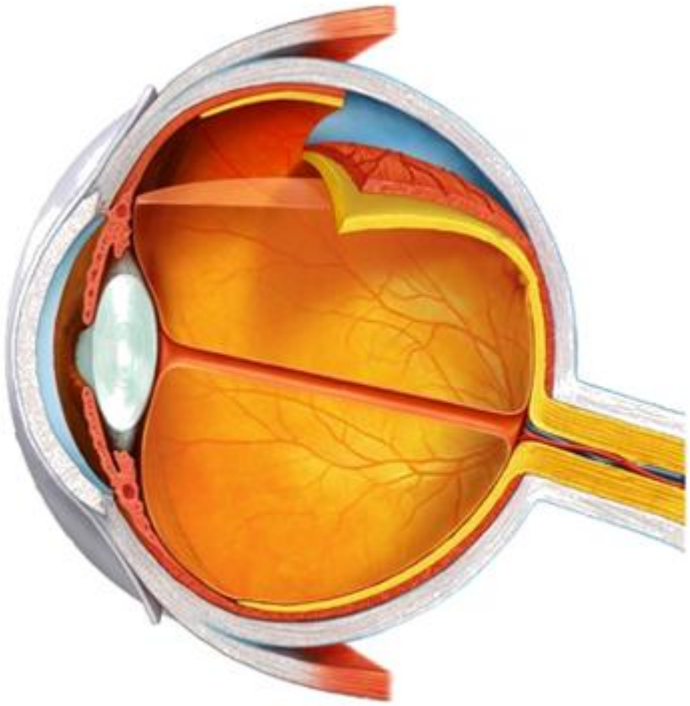
What about SA?

- Approximately 2.65 million South Africans will have glaucoma by 2020.

What is glaucoma?

- Glaucoma is a progressive disease which affects the
- optic nerve
- Leads to irreversible blindness
- Common cause is a rise in intraocular pressure (IOP)





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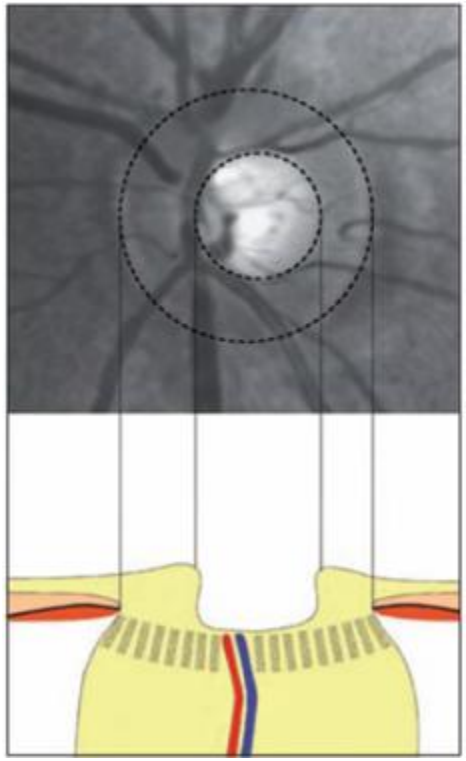
- Trobe, J., 1915. Acute_Angle_Closure-glaucoma.jpg, Available at: http://en.wikipedia.org/wiki/File:Acute_Angle_Closure-glaucoma.jpg [Accessed August 28, 2012].

Background

How is glaucoma diagnosed?

- An elevated IOP is the primary risk indicator for glaucoma
- during routine optomotery check ups
- Glaucoma progression is tested using two diagnostic tools:
  - Structural integrity of the optic nerve
  - Degradation of visual field



Glaucoma management?

- Most common treatment is to lower the IOP
- Three methods:
  - Medical therapy
  - Laser therapy
  - Surgery

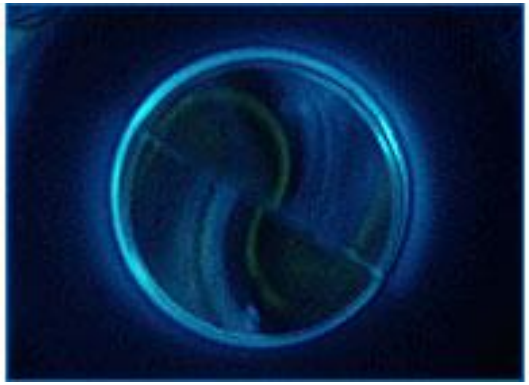
INTRAOCULAR PRESSURE IS IMPORTANT

Williams, S.E.I., 2007. Glaucoma. Continuing Medical Education, 25(10), pp.464–468.

Background

How is IOP measured?

- Goldmann applanation tonometry is the most common method
- Measures the indentation resistance of the cornea to estimate IOP, at an applanation diameter of 3.06mm



Associated pitfalls?

- Corneal thickness and material properties are known to influence the IOP reading when they deviate from the norm
- A patients age is also considered a factor, as the cornea becomes more stiff with age

- Anon, RTEmagicC_Eye_tonometer_02.jpg.jpg (JPEG Image, 196 × 140 pixels) - Scaled (0%), Available at: http://www.haag-streit.com/uploads/RTEmagicC_Eye_tonometer_02.jpg.jpg [Accessed September 6, 2012b].
- Anon, RTEmagicC_tonoView_02.jpg.jpg (JPEG Image, 196 × 140 pixels) - Scaled (0%), Available at: http://www.haag-streit.com/uploads/RTEmagicC_tonoView_02.jpg.jpg [Accessed September 6, 2012c].
- Kniestedt, C. et al., November. Tonometry Through the Ages. Survey of Ophthalmology, 53(6), pp.568–591.

Study objectives

Improve the accuracy of glaucoma screening

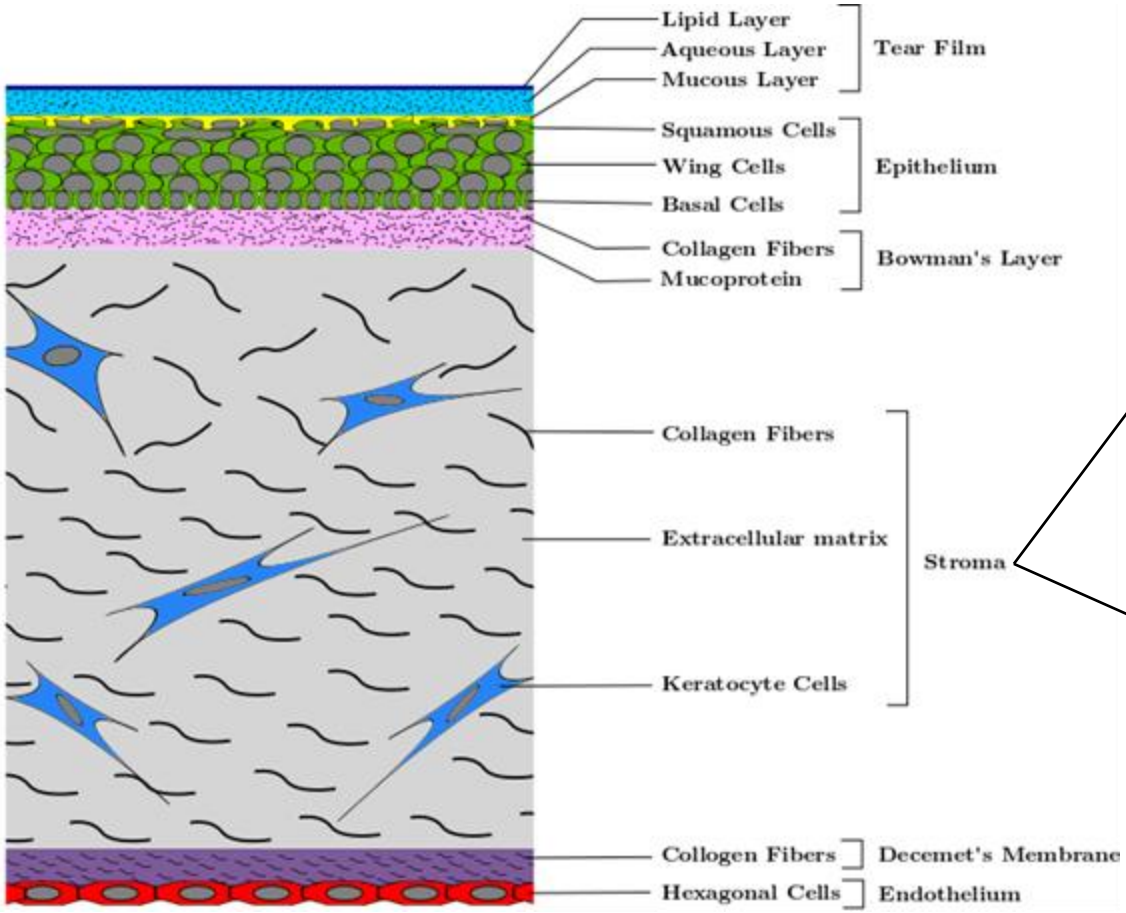
Numerically simulating Goldmann applanation tonometry

Determine a relationship between the corneal thickness, properties and IOP

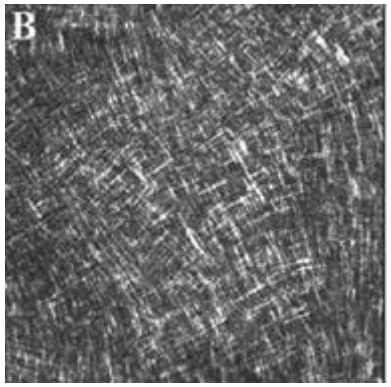
Estimate the IOP more accurately using reduced order modelling techniques

- Developing a finite element model of the cornea
- Calibrate the corneal properties with experimental inflation test data
- Simulate Goldmann applanation tonometry
- Extract the ocular response history

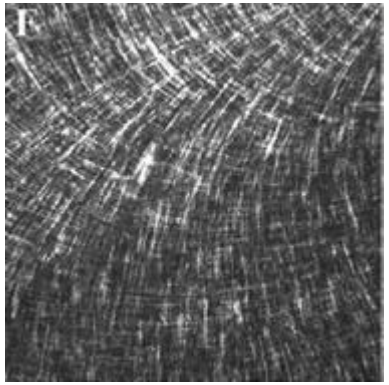
Anatomy of the human cornea



Central



Peripheral



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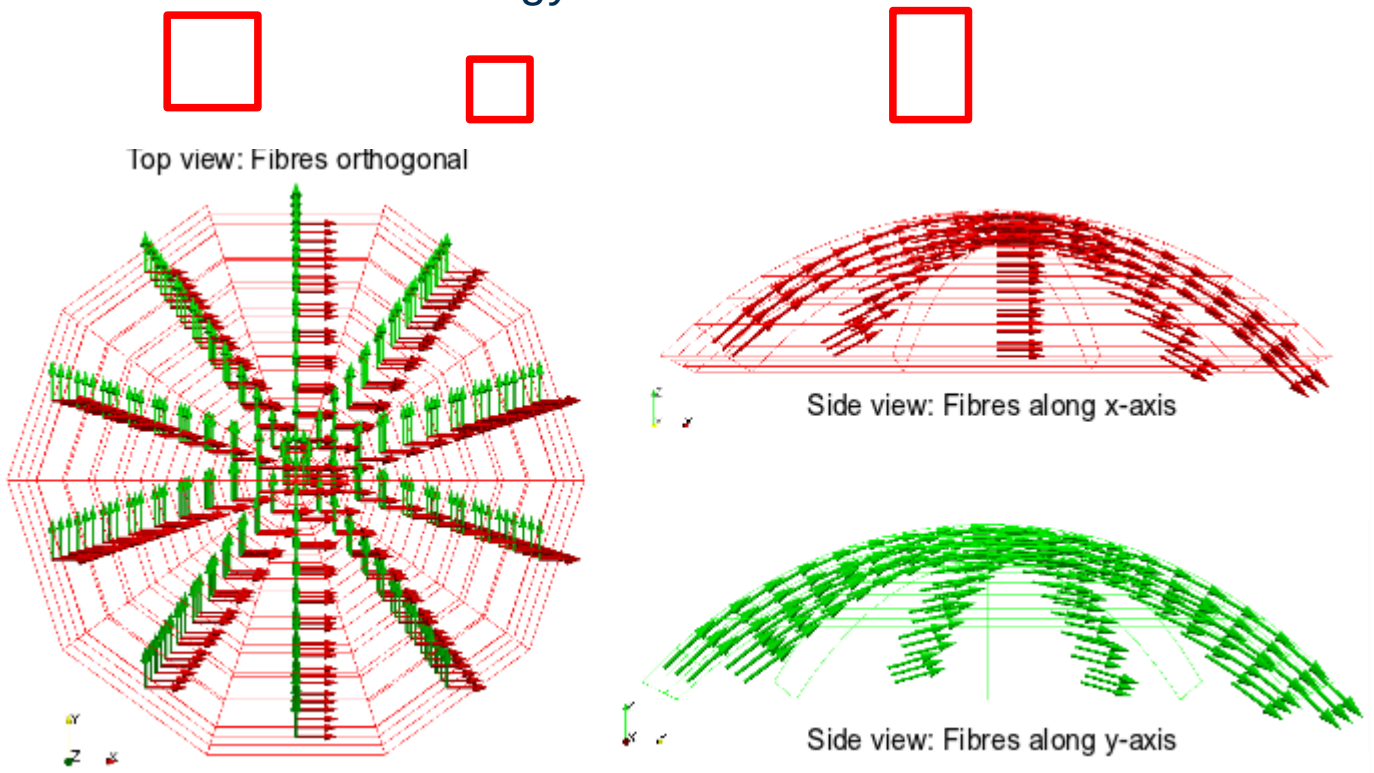
Finite element model of the cornea

Rotationally symmetric conicoid:

Elastic reinforced fiber strain energy function:



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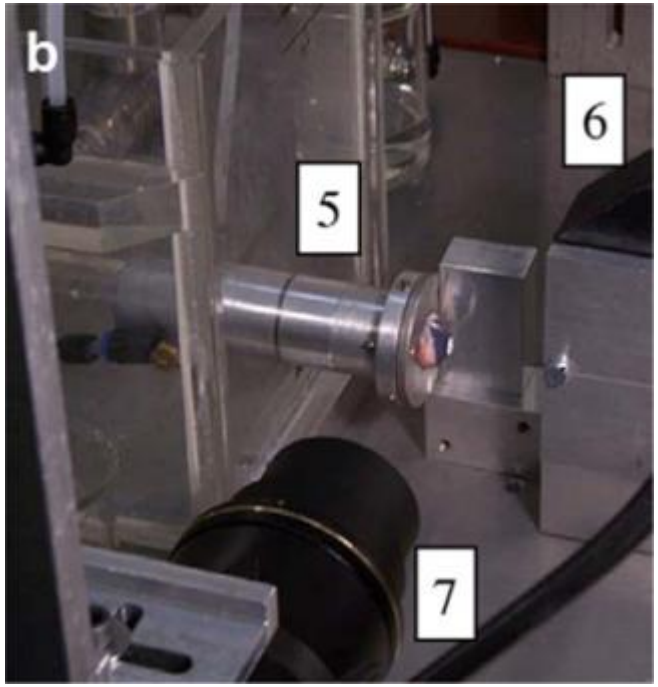
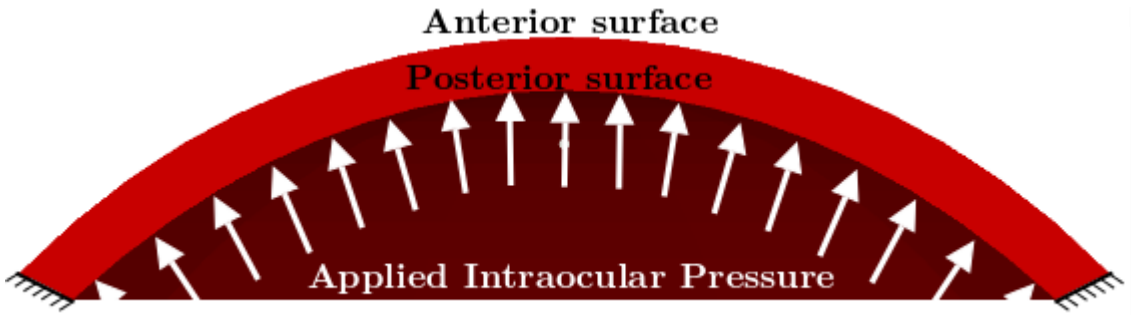
- Science, 38(2), pp.311–320.
- Dhondt, G.D.C., 2004. The finite element method for three-dimensional thermomechanical applications, John Wiley and Sons.

Inflation test

Experimental setup

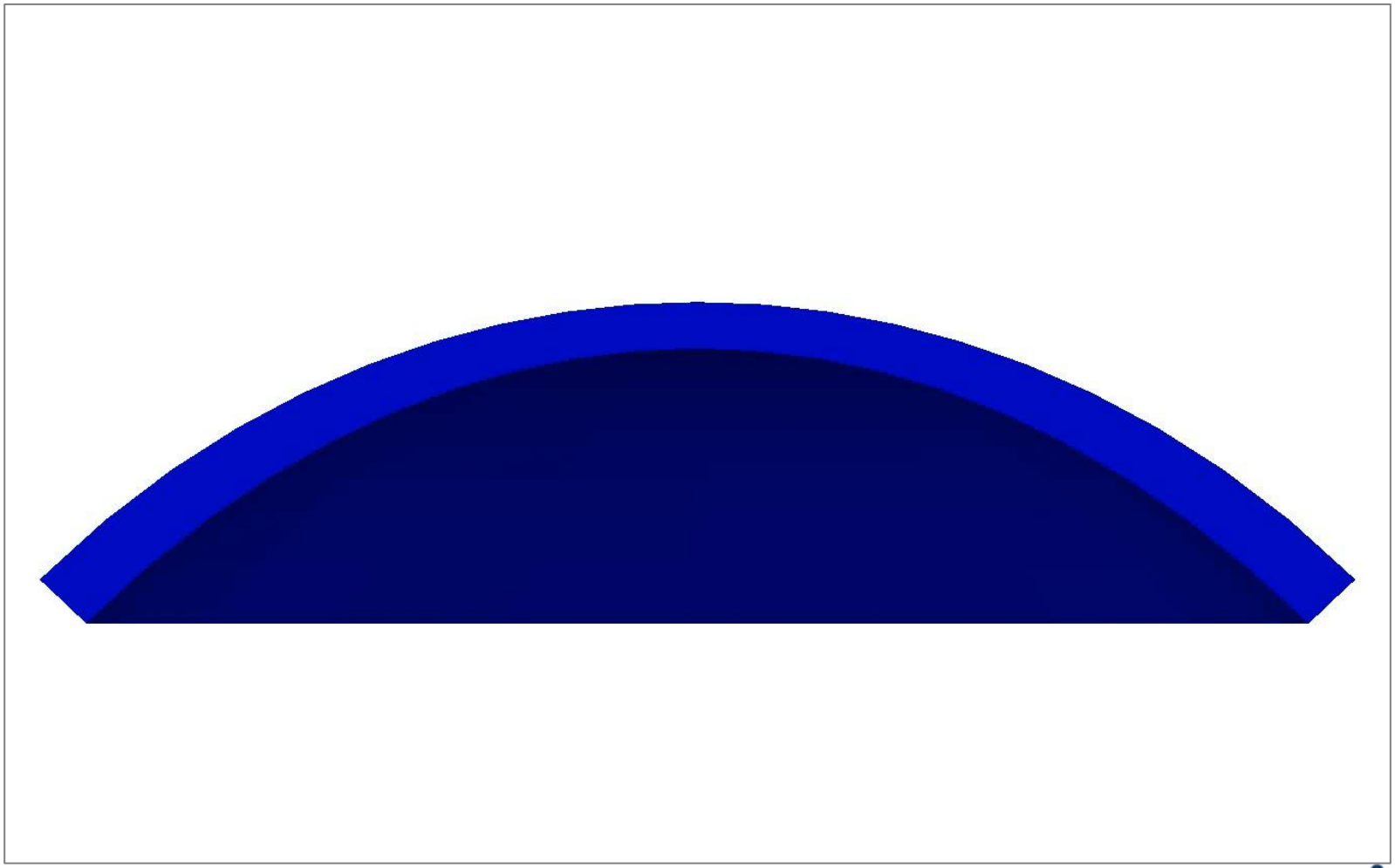


FE boundary conditions



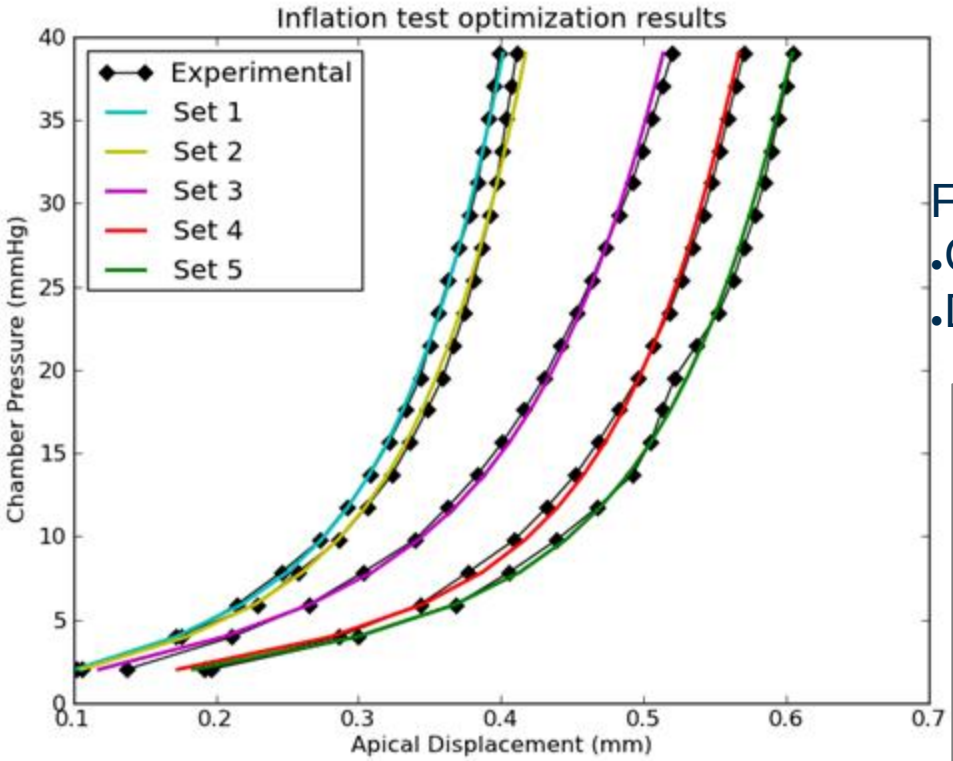
Elsheikh, A., Alhasso, D. & Rama, P., 2008. Assessment of the epithelium's contribution to corneal biomechanics. Experimental Eye Research, 86(2), pp.445–451.

Inflation Test



Calibration of material coefficients

Minimise the root mean square error:



Fixed:

- C1 = 0.004 MPa
- D1 = 0.4

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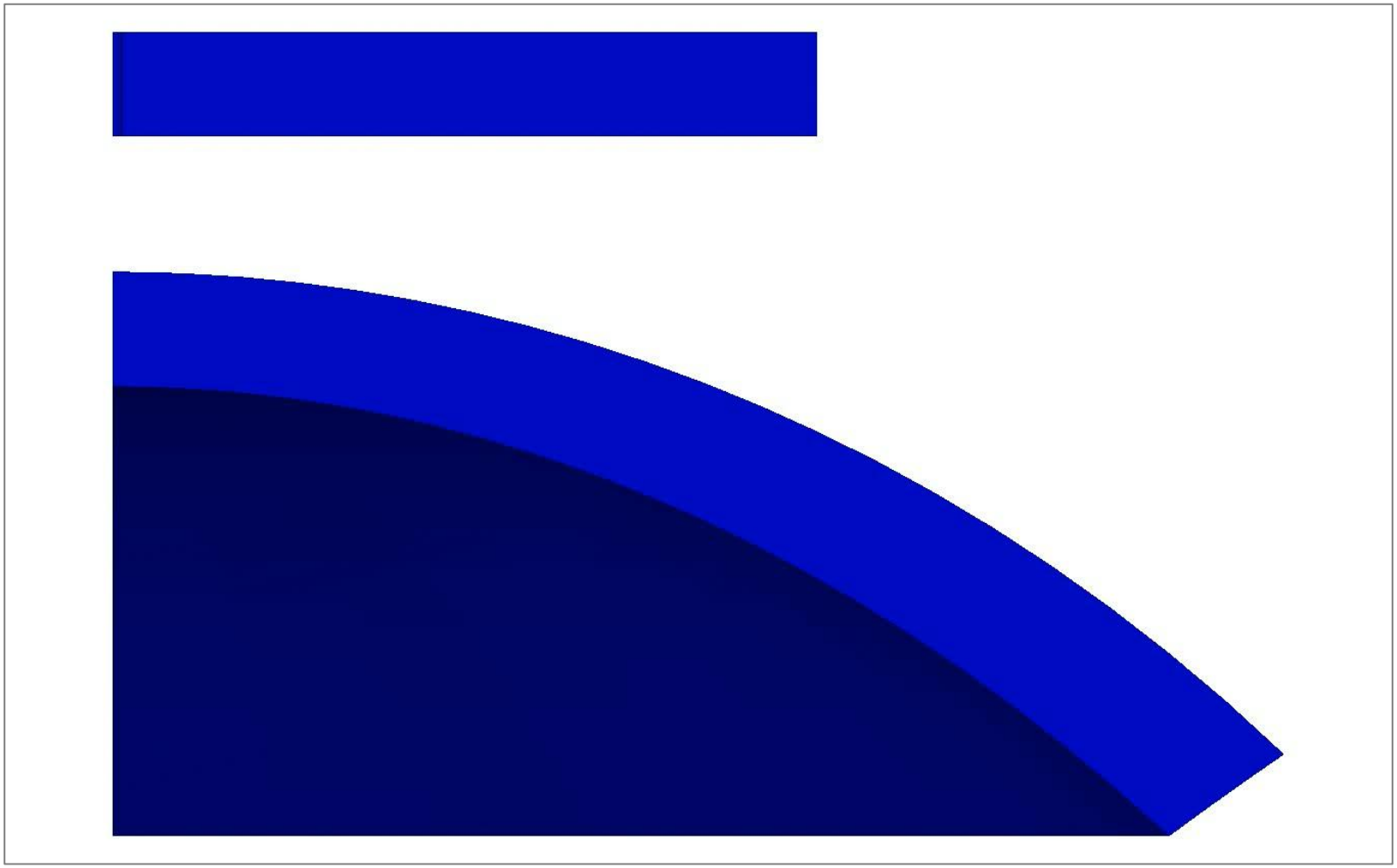
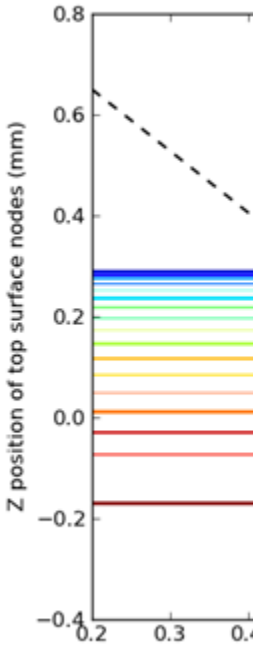
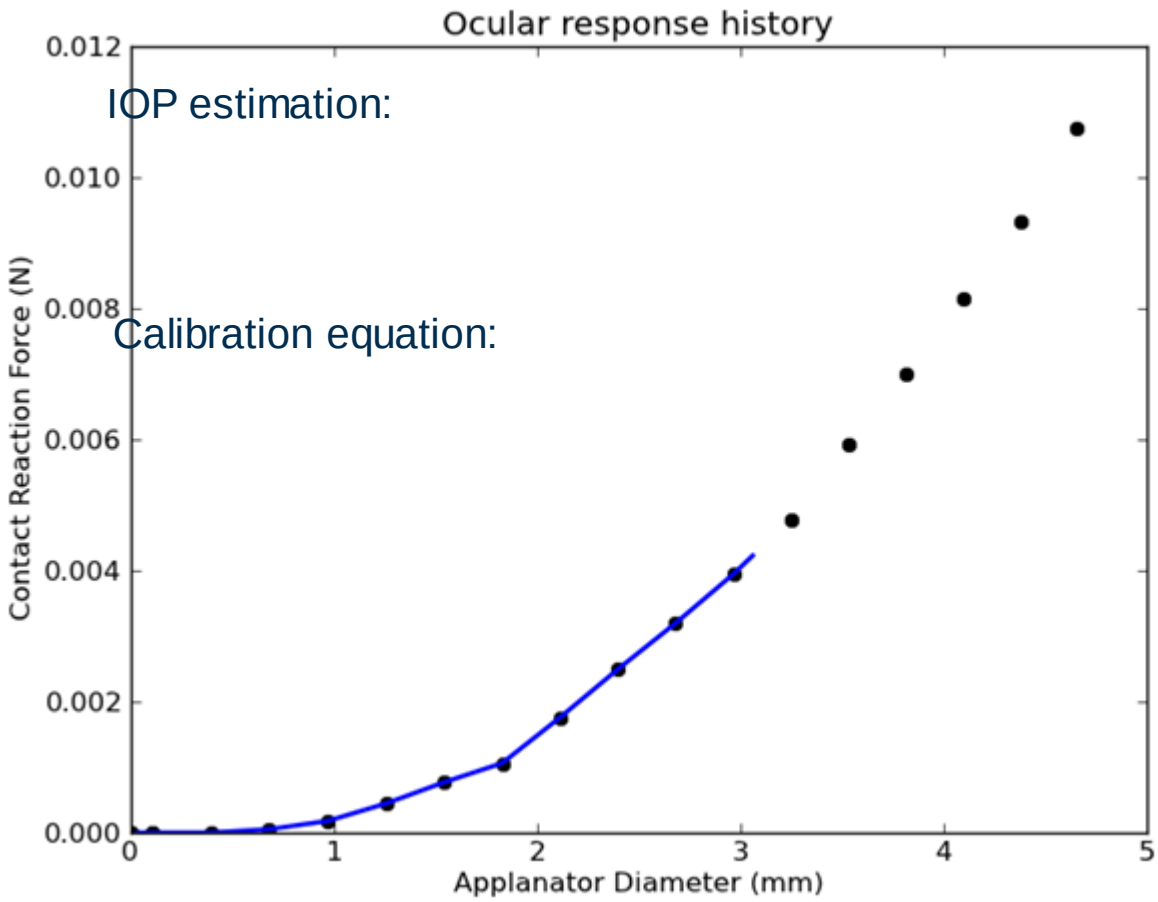
Bryant, M.R. & McDonnell, P.J., 1996. Constitutive Laws for Biomechanical Modeling of Refractive Surgery. Journal of Biomechanical Engineering, 118(4), pp.473–481.

Goldmann Applanation Tonometry



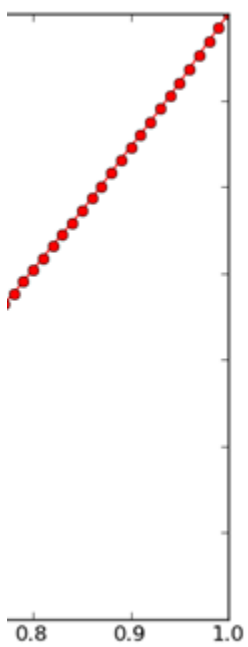
How do we extract the ocular response history?



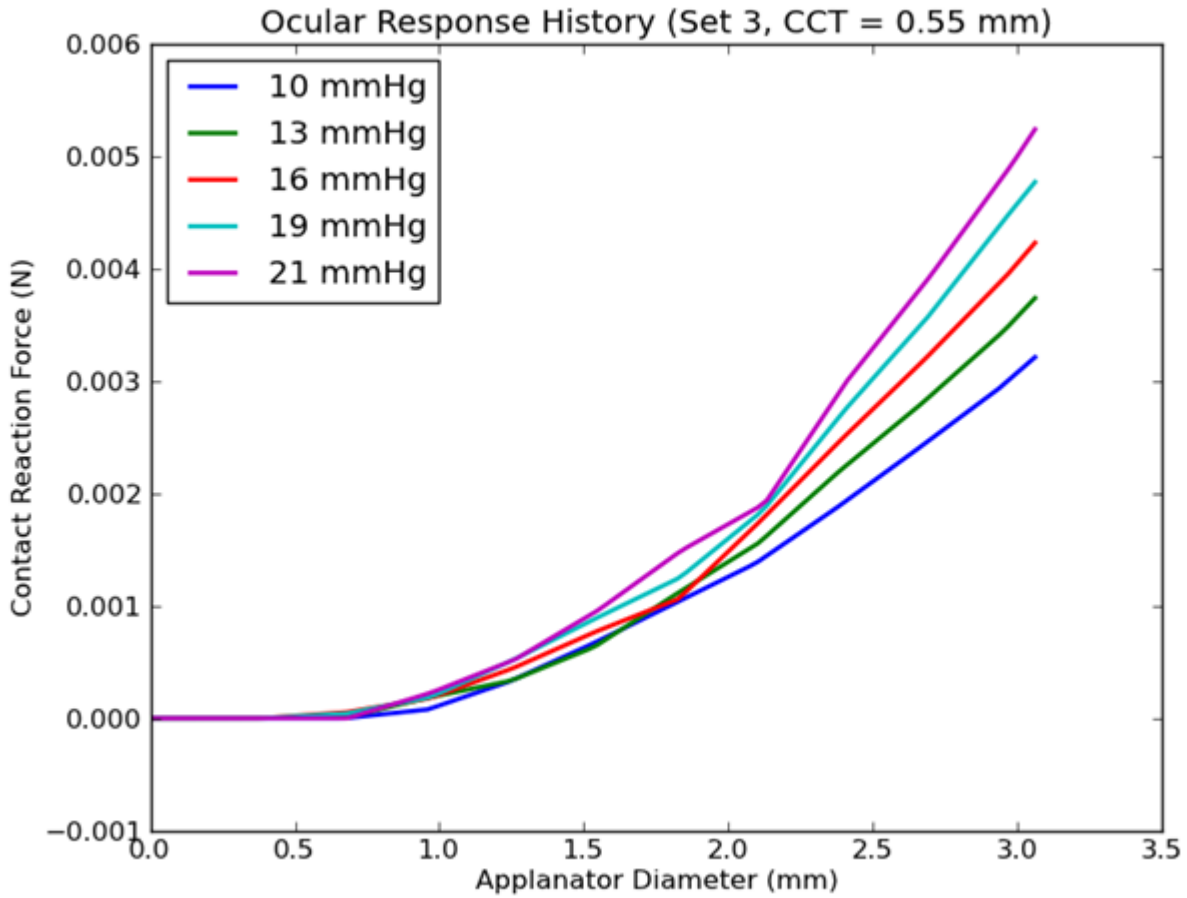


IOP estimation:

Calibration equation:



Variation due to intraocular pressure



Optimise for the absolute error:

IOP estimation using calibrated diameter:

21.43 mmHg

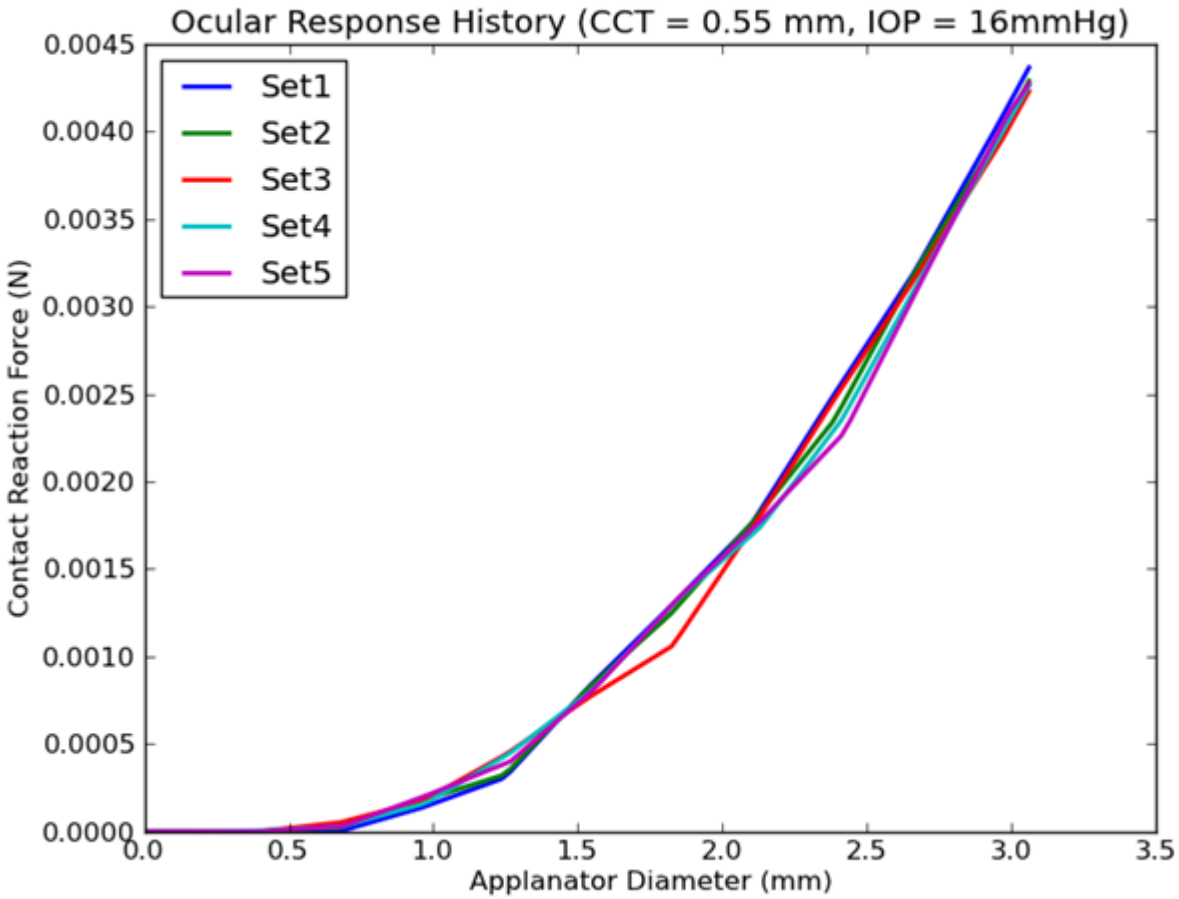
18.80 mmHg

15.76 mmHg

13.01 mmHg

10.06 mmHg

Variation due to material properties



IOP estimation using calibrated diameter:

16.53 mmHg

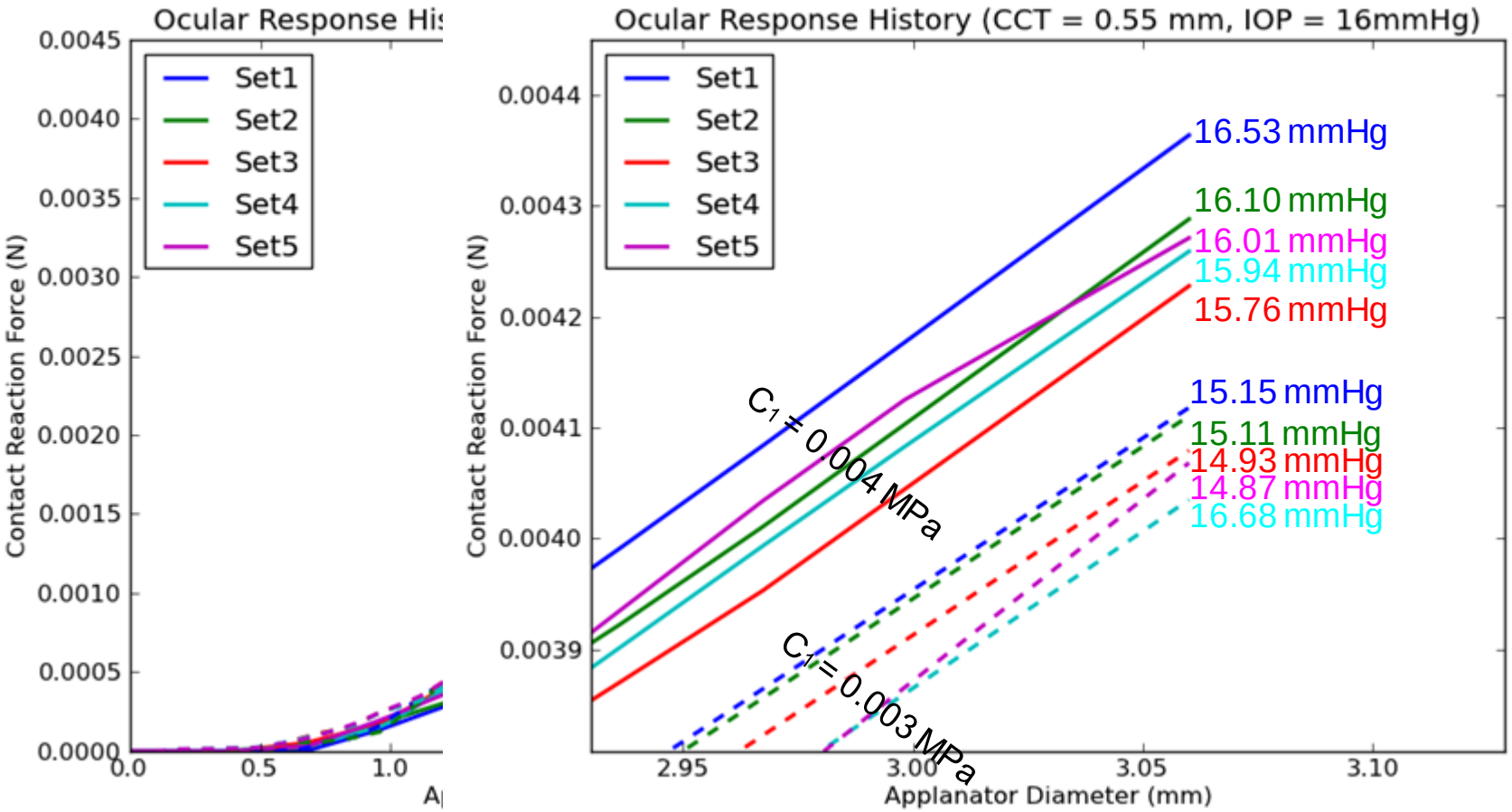
16.10 mmHg

15.76 mmHg

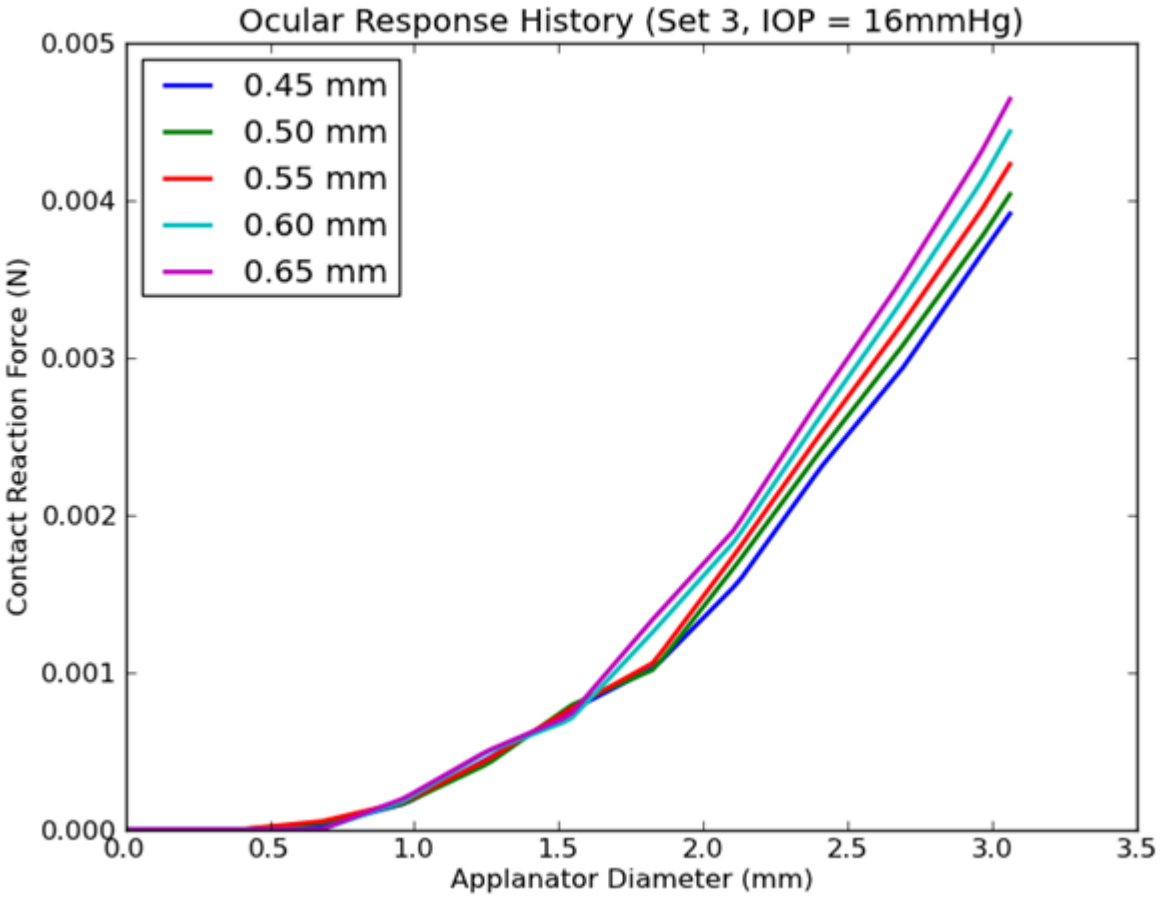
15.94 mmHg

16.01 mmHg

Variation due to material properties



Variation due to corneal thickness



IOP estimation using calibrated diameter:

18.09 mmHg

16.93 mmHg

15.76 mmHg

14.69 mmHg

14.00 mmHg

Conclusions

What did we do?

- Developed a finite element model of the human cornea, which includes the complex structure
- Calibrated the material coefficients with experimental inflation test data by assuming that only the fibers contribute to corneal stiffness, and therefore the cornea elastin is the same for all corneas
- Simulated Goldmann applanation tonometry and obtained an ocular response history, which we then numerically calibrated as Goldmann did

What did we learn?

- The fibers contribute very little to the corneal stiffness and the elastin actually contributes the most
- Central corneal thickness and intraocular pressure influences the Goldmann tonometer measurement

Future work

In this study

- Study the effects of numerical model assumptions on the Goldmann applanation tonometry simulation
- Inversely estimate the intraocular pressure using reduced order modelling techniques

Overall project

- Apply these techniques to the air puff tonometer which is a non contact method
- Improve the calibration process of the numerical model by also calibrating for material coefficients using strip extensometry data
- Improve the current material model to include the visco-elastic effects of the cornea
- Refine the reduced order modelling techniques used to inversely estimate intraocular pressure

Thank you

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