Modelling Goldmann applanation tonometry to improve accuracy of glaucoma screening

Emerging Researcher Symposium

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

Background

Glaucoma is a progressive disease which affects the optic nerve, leads to irreversible blindness, and the common cause is a rise in intraocular pressure (IOP).

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).

[References]

- Anon. 2133_eye_anatomy_label_v2_700.jpg (JPEG Image, 700 × 526 pixels) - Scaled (0%), Available at: [link]
- Boson, M. Glaucoma-symptoms.jpg, Available at: [link] [Accessed August 27, 2012].
Background

How is glaucoma diagnosed?

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

Gluacoma management?

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

INTRAOCULAR PRESSURE IS IMPORTANT

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 patient's age is also considered a factor, as the cornea becomes more stiff with age.

References:

Anon. RTEmagicC_Eye_tonometer_02.jpg. (JPEG Image, 196 x 140 pixels) - Scaled (0%). Available at: http://www.haag-streit.com/uploads/RTEmagicC_Eye_tonometer_02.jpg.jpg [Accessed September 6, 2012b].

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Study objectives

Improving 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

Finite element model of the cornea

Rotationally symmetric conicoid:

Elastic reinforced fiber strain energy function:

Top view: Fibres orthogonal

Side view: Fibres along x-axis

Side view: Fibres along y-axis


Inflation test

Experimental setup

FE boundary conditions

Inflation Test
Calibration of material coefficients

Minimise the root mean square error:

Fixed:
- \( C_1 = 0.004 \text{ MPa} \)
- \( D_1 = 0.4 \)

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

Ocular Response History (CCT = 0.55 mm, IOP = 16 mmHg)

- Set1
- Set2
- Set3
- Set4
- Set5

Contact Reaction Force (N) vs. Applanator Diameter (mm)

- $C_1 = 0.004 \text{ MPa}$
- $C_1 = 0.003 \text{ MPa}$

- 16.53 mmHg
- 16.10 mmHg
- 16.01 mmHg
- 15.94 mmHg
- 15.76 mmHg
- 15.15 mmHg
- 15.11 mmHg
- 14.93 mmHg
- 14.87 mmHg
- 16.68 mmHg
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