Numerical investigation of the contribution of zonules in the accommodation of the human lens using the Finite Element Method

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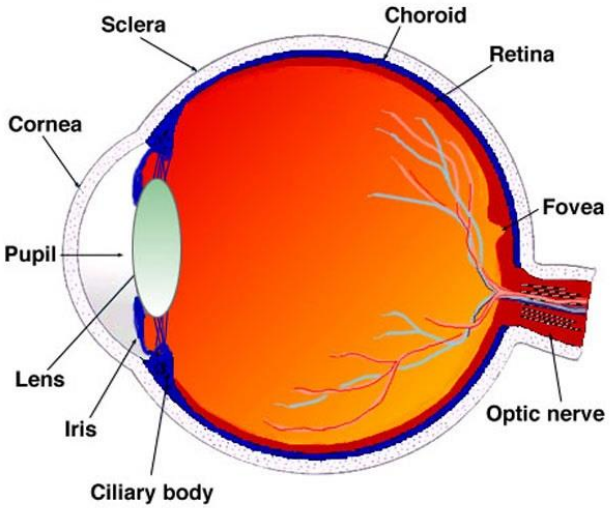
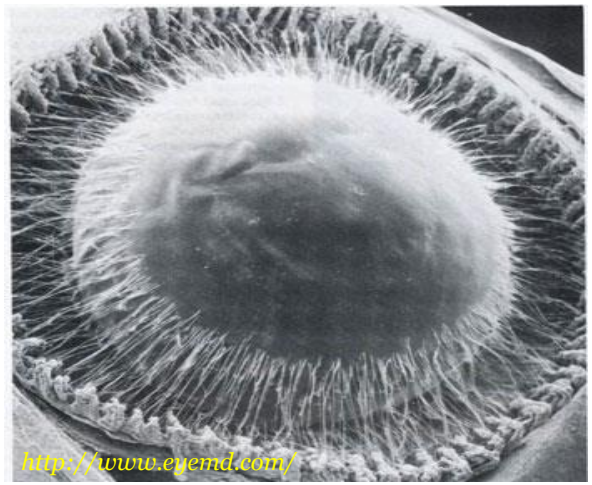
Anatomy of human eye



http://www.skybrary.aero/index.php/Vision_(OGHFA_BN)



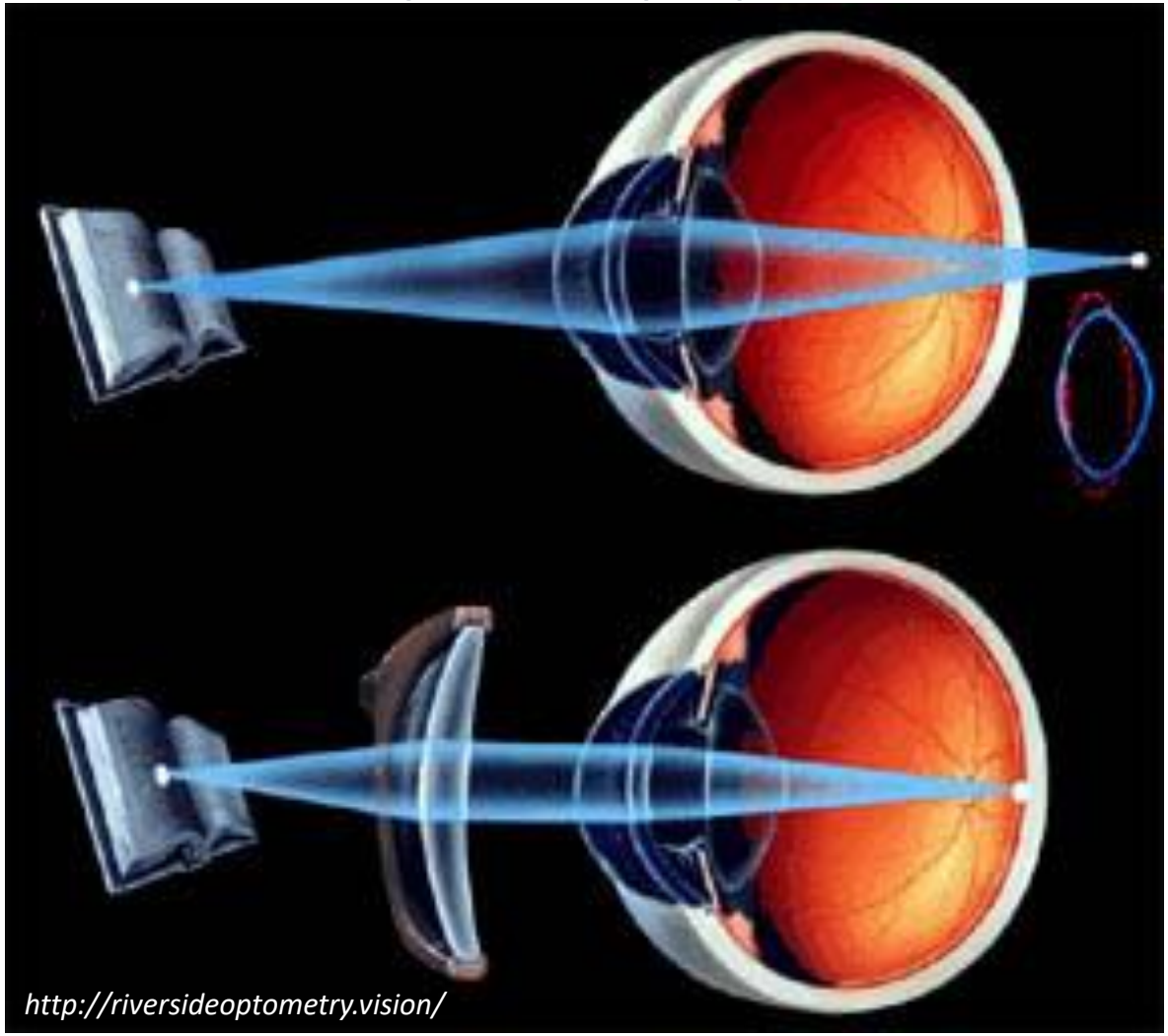
Eye:

- Fibrous layer: cornea and sclera
- Vascular layer: choroid, ciliary body, iris (pupil)
- Nervous layer: retina

Lens:

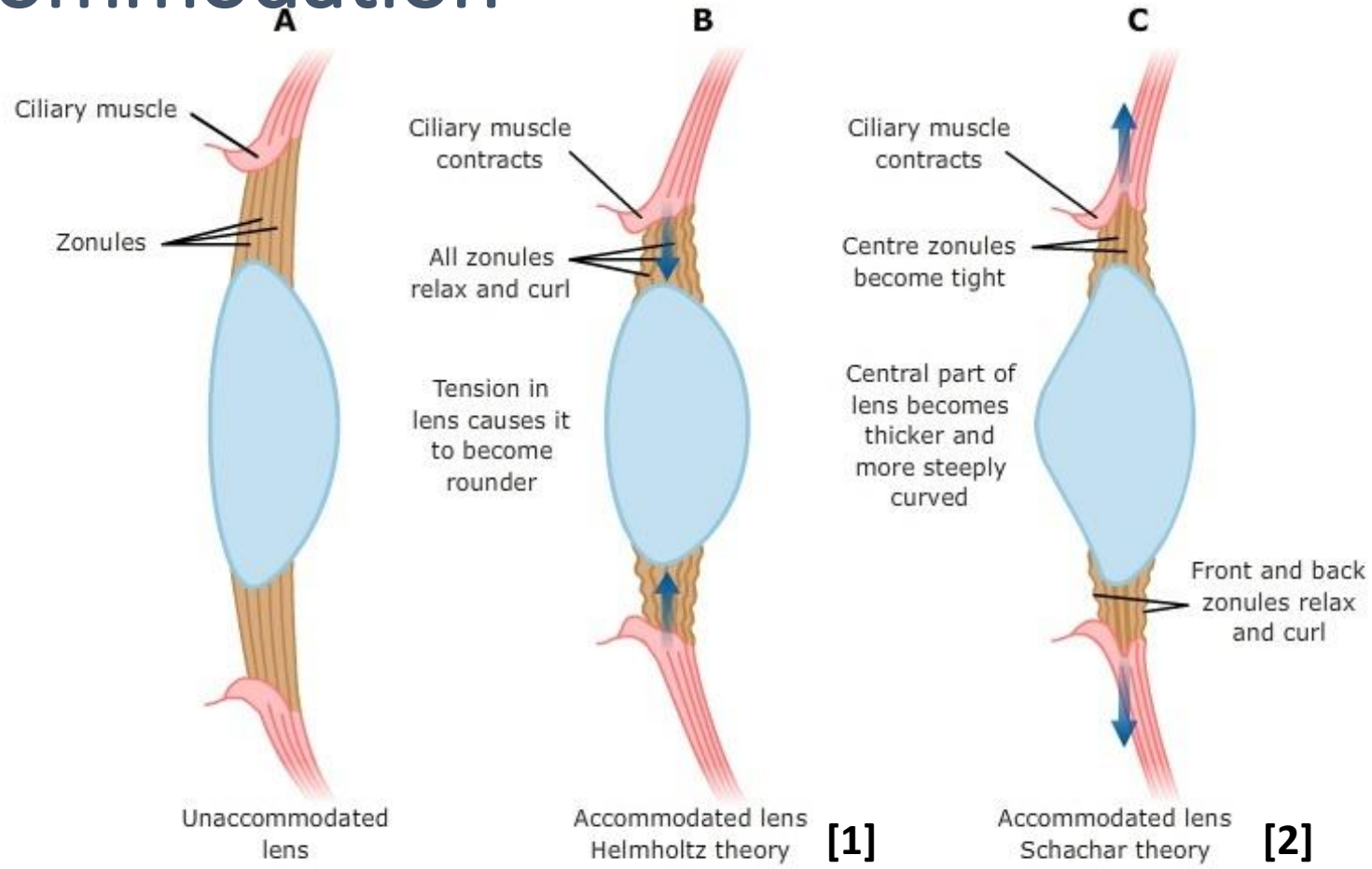
- The lens is held in place by zonular fibres
- Zonular fibres are attached to lens peripheral zone

What is presbyopia



- Sometime after the 40th birthday, it is more difficult to read
- With age, the lens gradually hardens and does not change shape
- Reading glasses with plus-power gives the eye the power it needs to see clearly

Accommodation



[1] Helmholtz, H. Uber die Akkommodation des Auges. *A. v. Graefe's Arch. Klin. Ophthalmol* **1**, 1–74 (1855)

[2] Schachar, R.A. Zonular function:a new hypothesis with clinical implications. *Ann.Ophthalmol.* **26**, 36–38(1994)

Why should we care about presbyopia

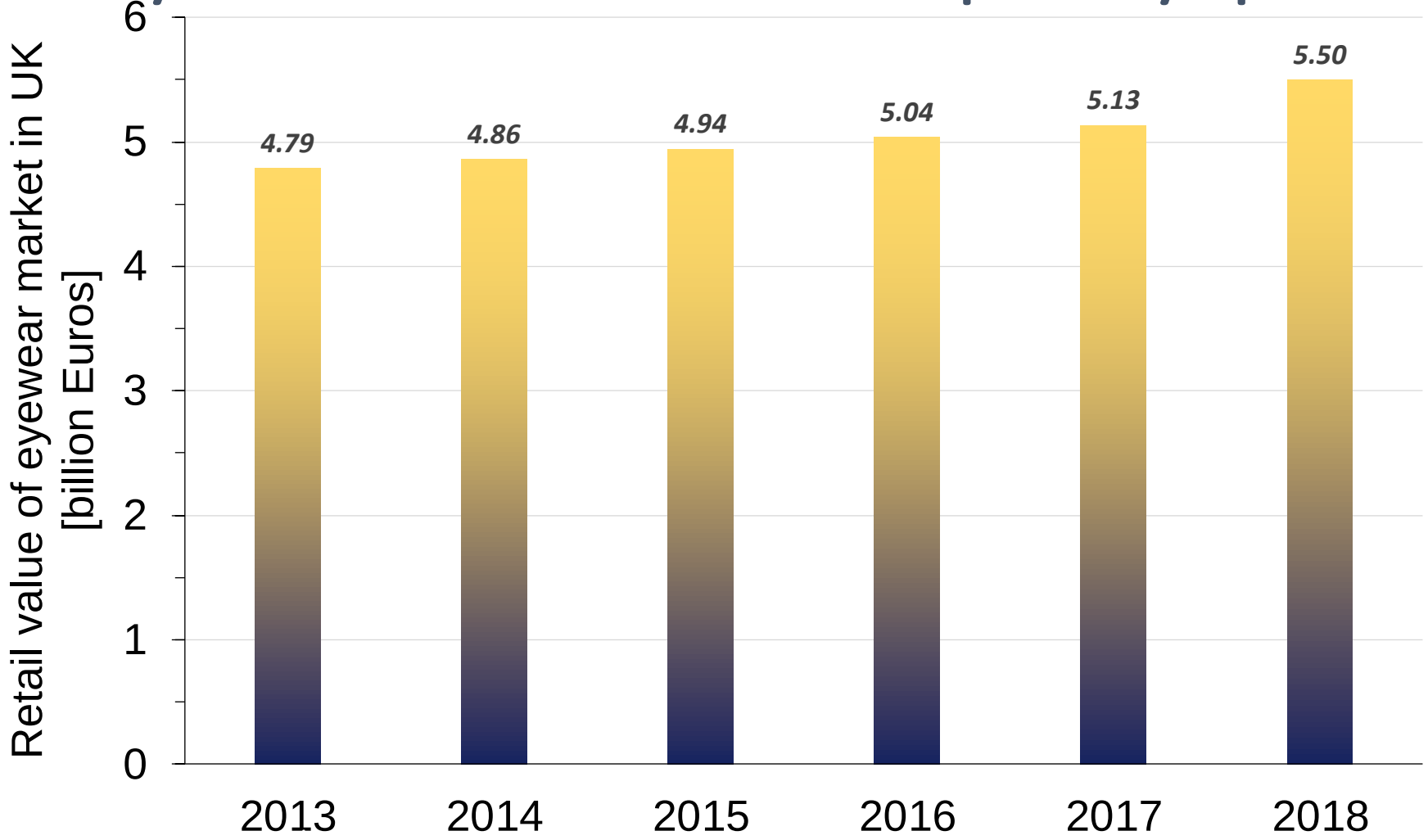
- 1.04 billion people globally with presbyopia in 2005
- 517 million had no spectacles or inadequate spectacles (of these, 410 million were prevented from performing near tasks in the way they required)
- Vision impairment from uncorrected presbyopia predominantly exists (94%) in the developing world

Holden BA, Fricke TR, Ho SM, et al. Global Vision Impairment Due to Uncorrected Presbyopia. Arch Ophthalmol. 2008;126(12):1731–1739. doi:10.1001/archopht.126.12.1731

- An estimated 23 million Britons suffer from presbyopia, or age-related long-sightedness

https://www.telegraph.co.uk/news/health/news/8754607/The-4000-eye-implant-to-replace-reading-glasses.html

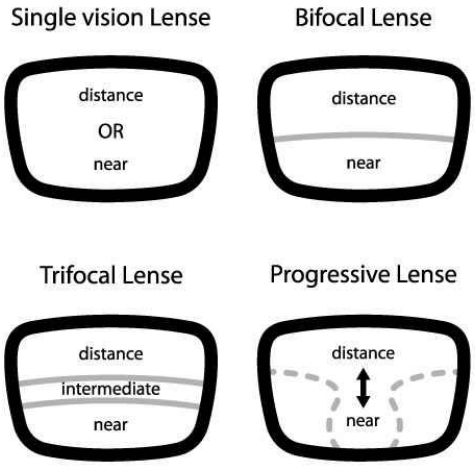
Why should we care about presbyopia



https://www.statista.com/statistics/491337/eyewear-united-kingdom-uk-market-value/glasses.html

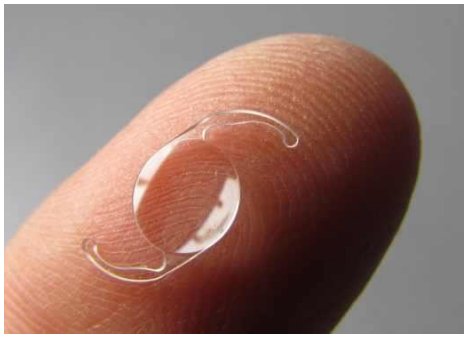
What can we do about it

FE Analysis: unique tool to analyse the response of eye lens

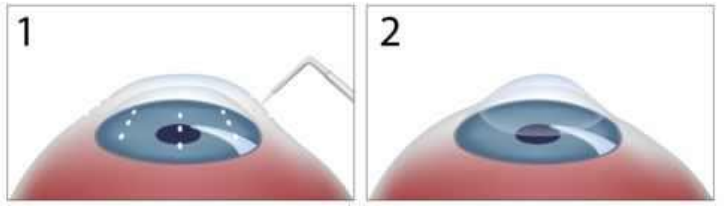


Reading glasses

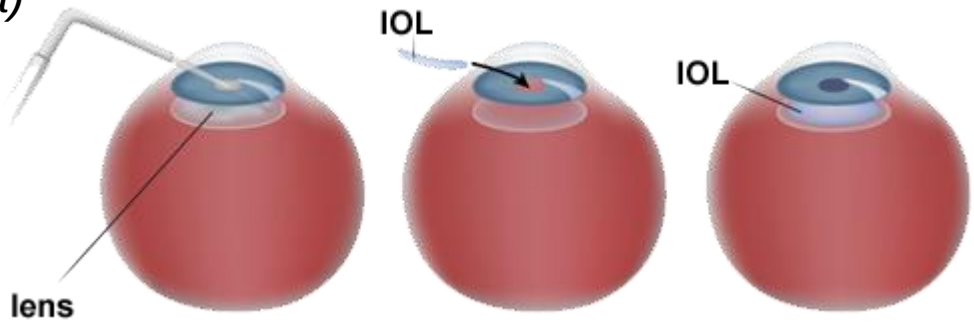
Contact lenses



Corneal inlays *(tiny lenses surgically placed in cornea)*

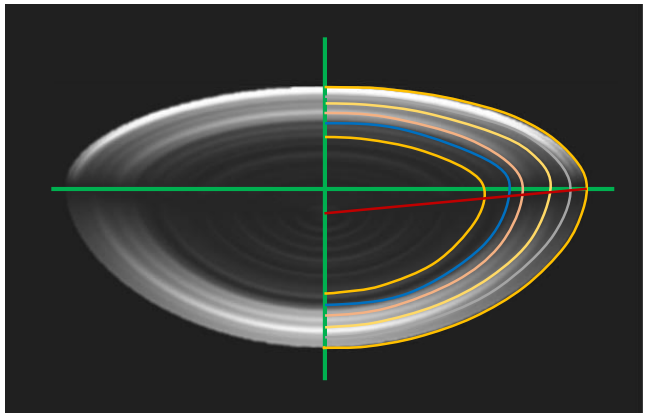


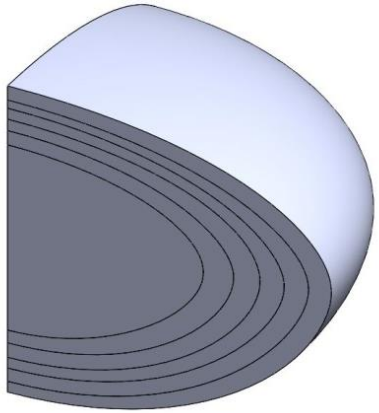
Conductive Keratoplasty



Refractive lens exchange (RLE): invasive procedure that involves replacing the natural lens of the eye with an artificial **I**ntra**O**cular **L**ens (IOL)

Geometry of FE lens models



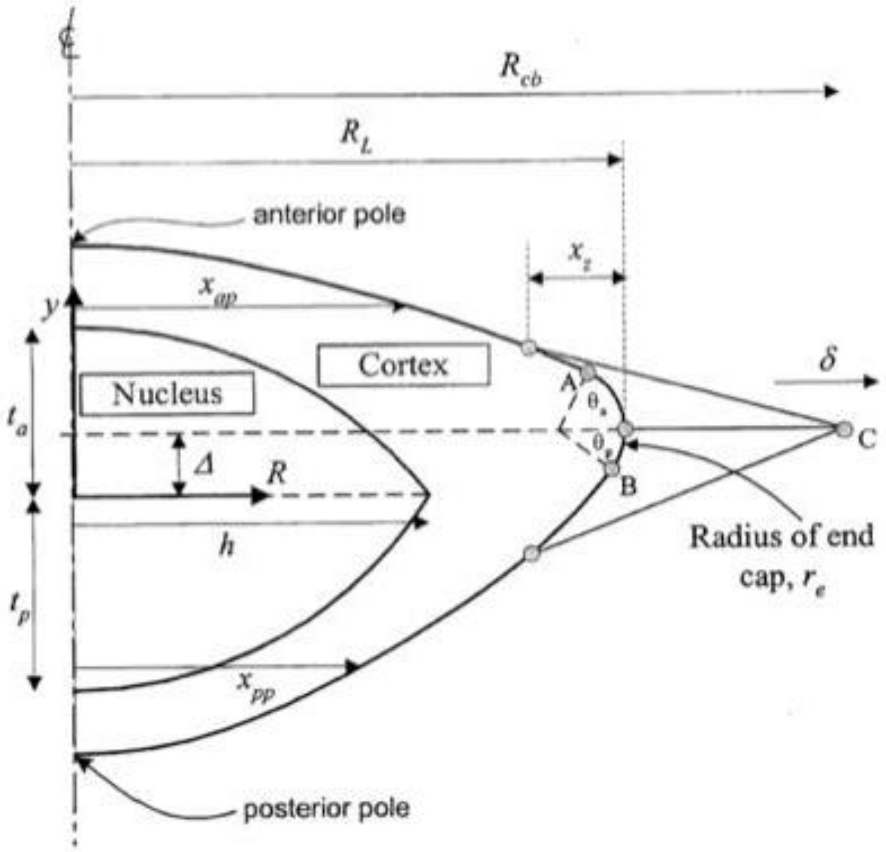


Refractive Index Profile **Optical Image** **Solid Model**

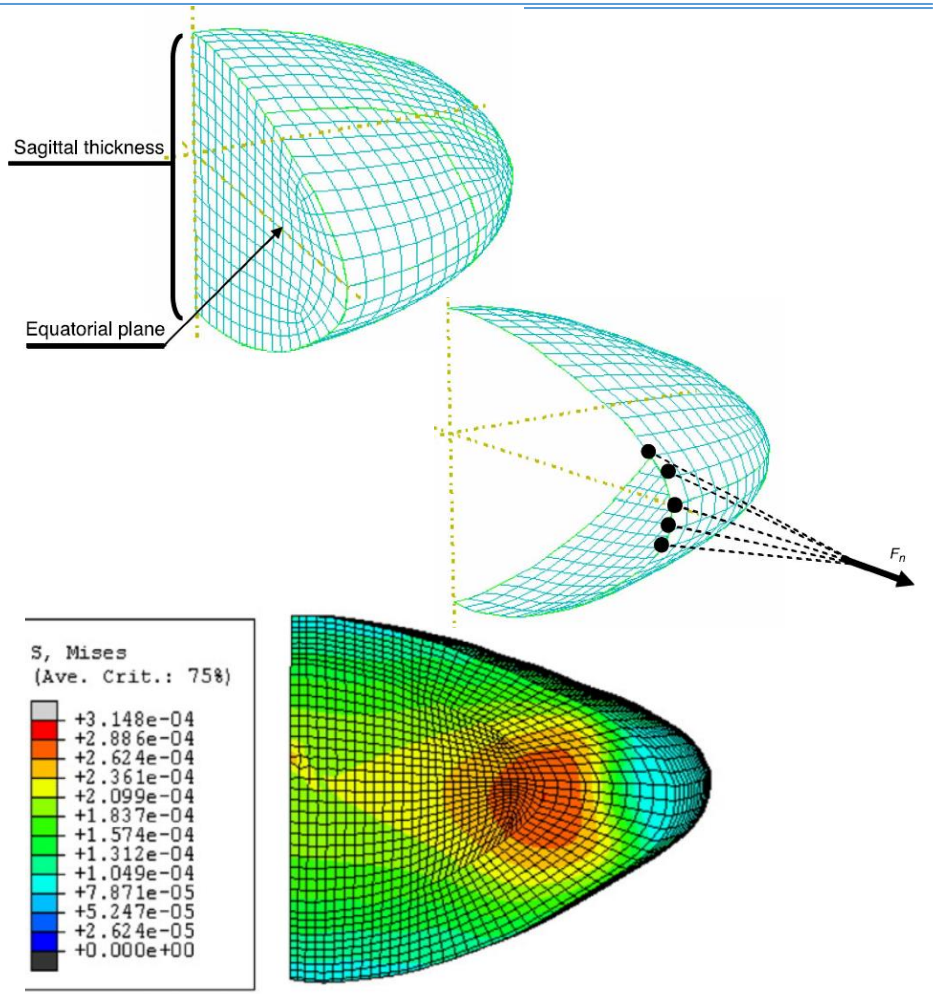
- ✓ Lens geometry (outer shape & internal cortical layers) can be obtained from optical measurements
- ✓ Both 3-D and axisymmetric Finite Element (FE) models can be developed
- ✓ Present work: axisymmetric / 16yo & 35yo lenses

[1] Bahrami M. et al, Exp Eye Res, 124:93-99, 2014.

FE models of eye lens



Burd HJ, Judge SJ, Cross JA. Numerical modelling of the accommodating lens. Vision Research. 2002;42:2235–2251.

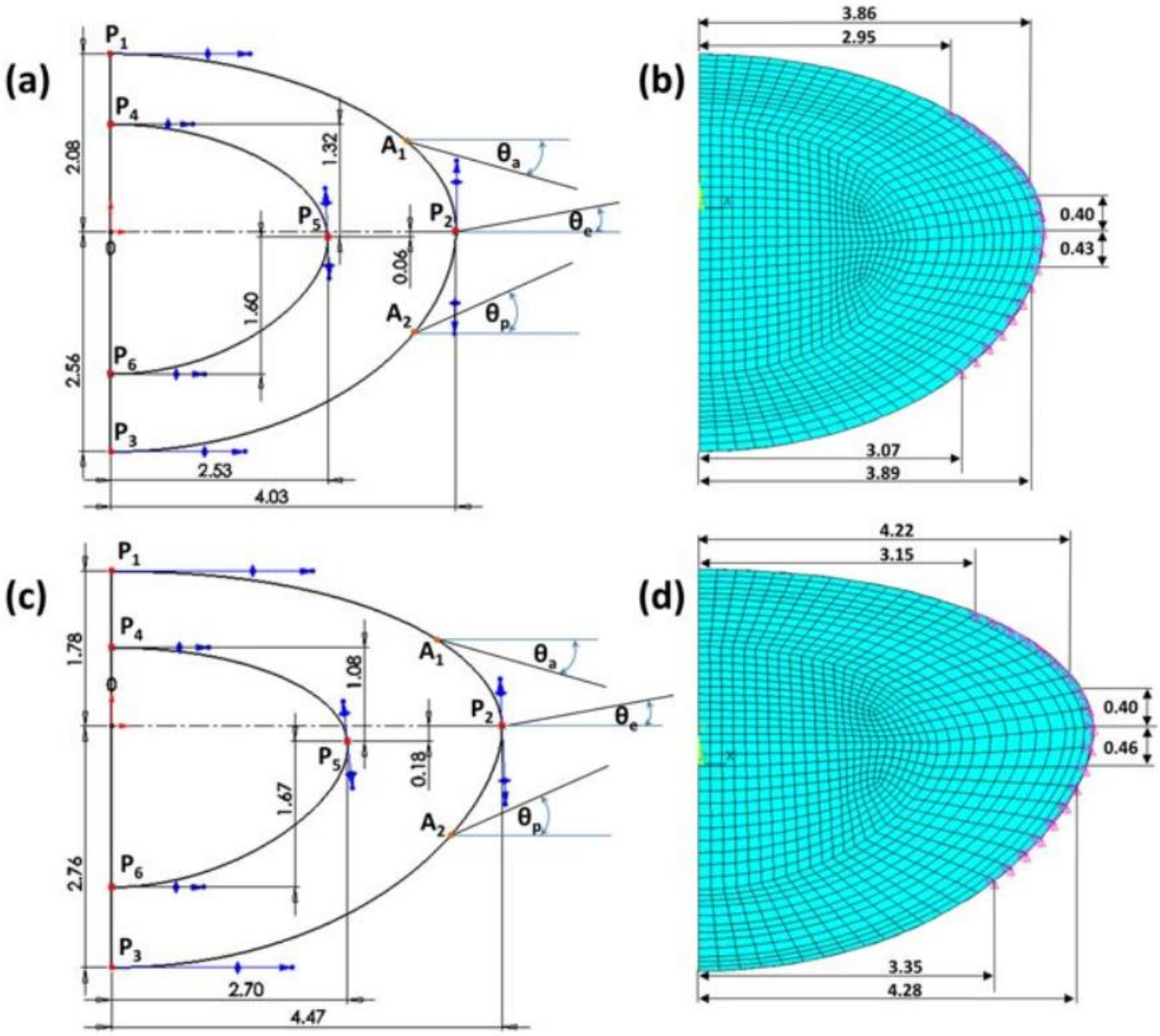


Belaidi, A. and Pierscioneck B.K.Journal of Vision (2007) 7(11):1, 1–12

Modelling zonular fibres

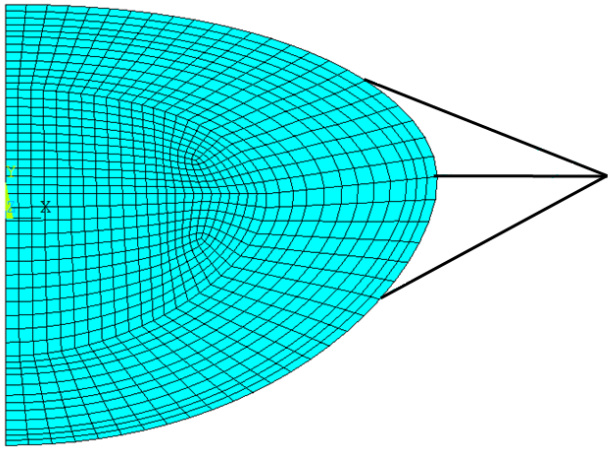
16-year-old lens:
(a) geometry
(b) FE model with anchorage regions of zonular fibres on lens capsule

35-year-old lens:
(c) geometry
(d) FE model with anchorage regions of zonular fibres on lens capsule

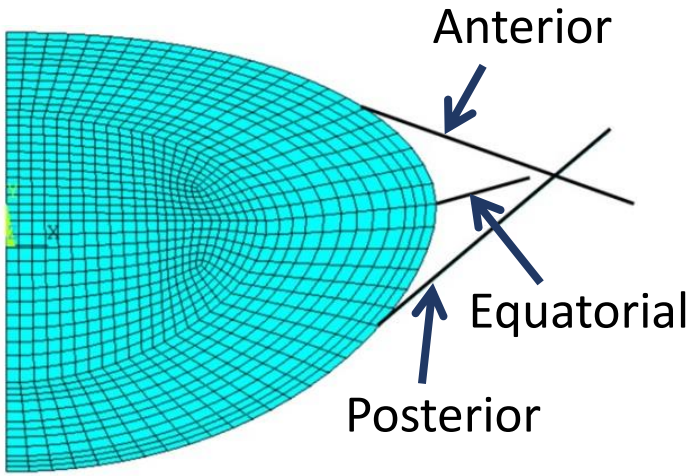


Wang K. et al, Sci Rep, 7, 2017.

Modelling zonular fibres



Bounded zonular fibres

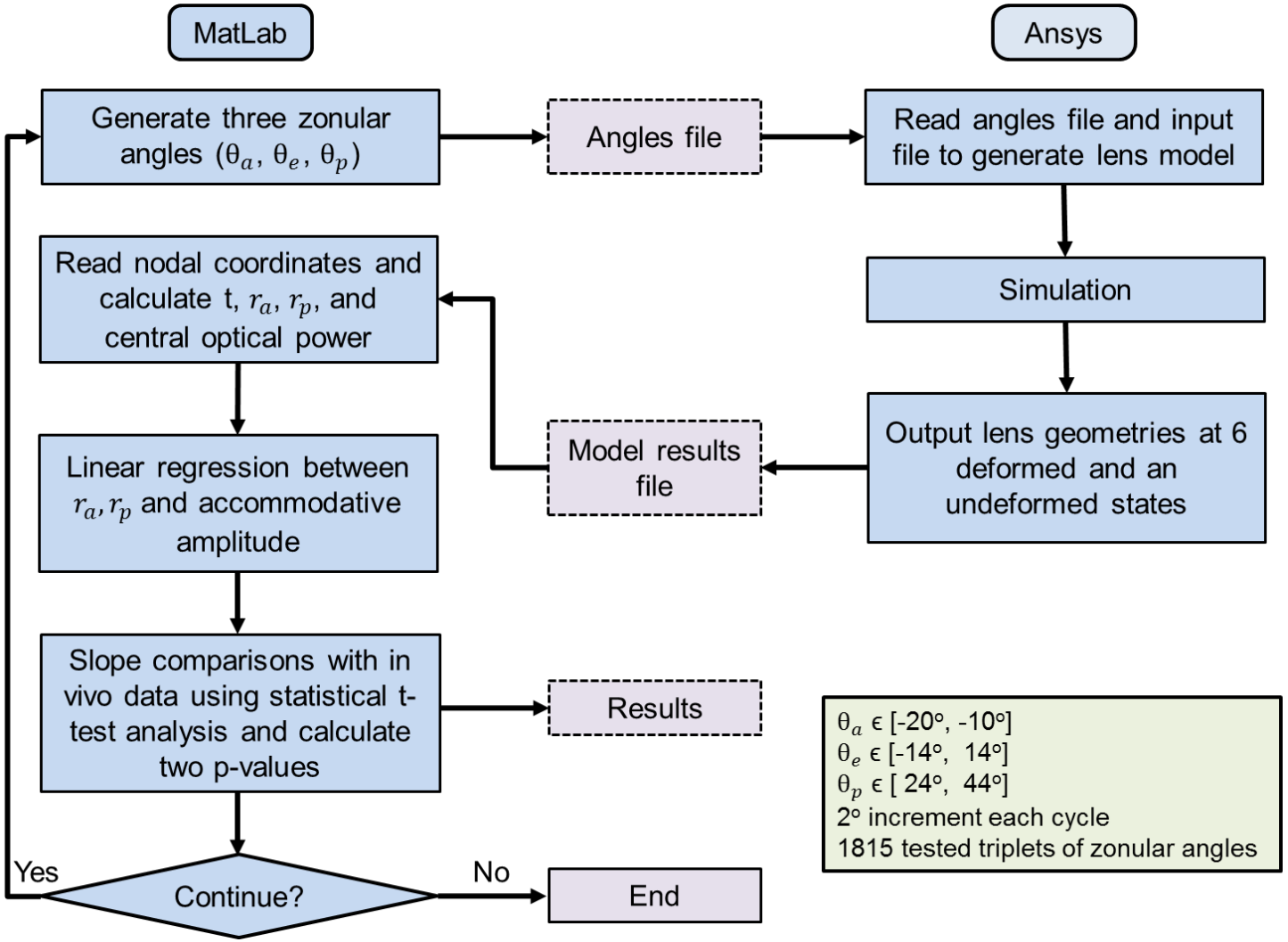


Split zonular fibres

- ✓ Material properties of lens nucleus and cortex: linear elastic, isotropic and homogenous.
- ✓ Poisson's ratio: 0.49 (nearly incompressible material)
- ✓ Nonlinear geometric simulations were performed.

Wang K. et al, Sci Rep, 6, 2016.

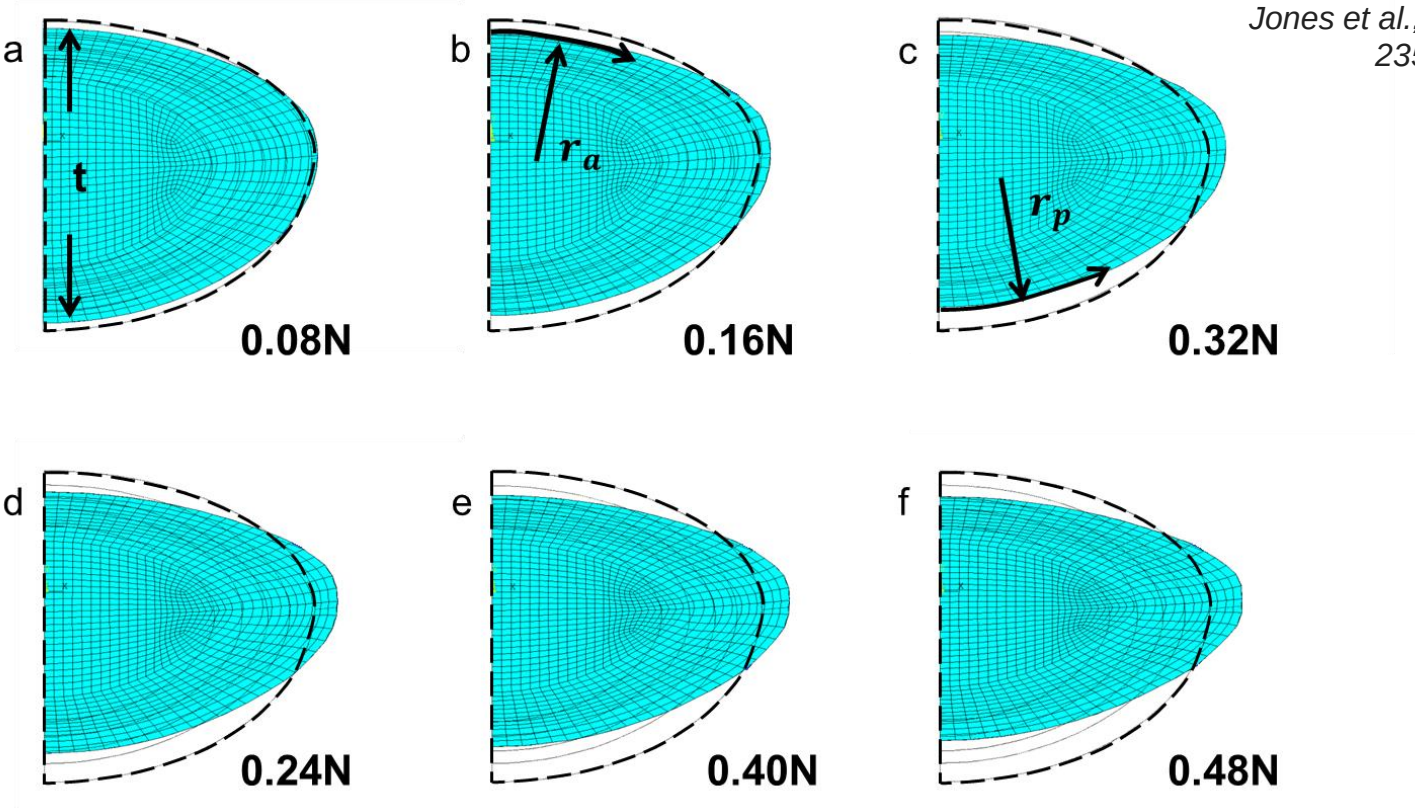
Exhaustive search scheme



Optical response of the model

Central Optical Power: COP = $\frac{n_1-n_2}{r_a} + \frac{n_1-n_a}{r_p} - \frac{(n_1-n_a)^2}{r_a r_p n_1}$, n_1=1.42, n_a=1.336

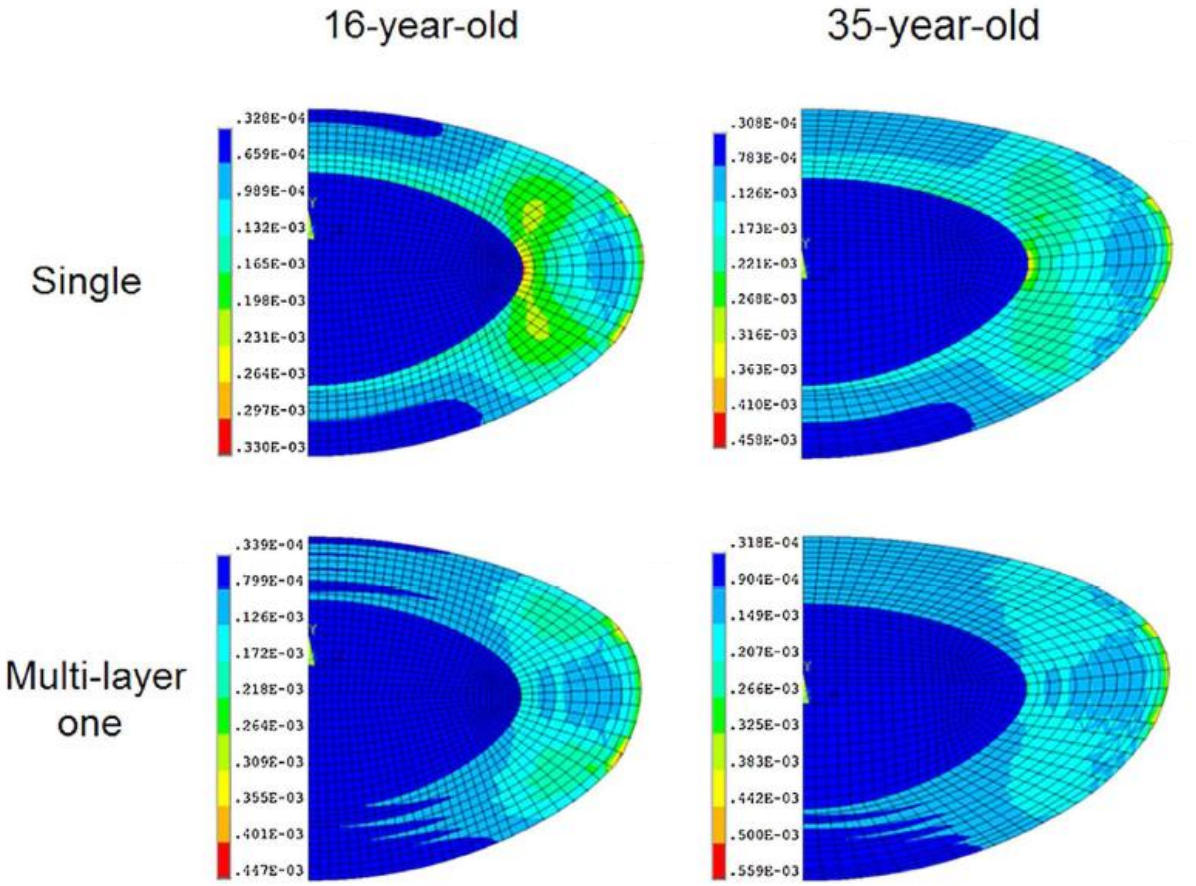
*Jones et al., Vision Res. **45**, 2352–2366 (2005).*



t: thickness r_a: RoC of anterior surface r_p: RoC of posterior surface

n_1: refractive index of aqueous humour n_2: refractive index of lens

Optical response of the model



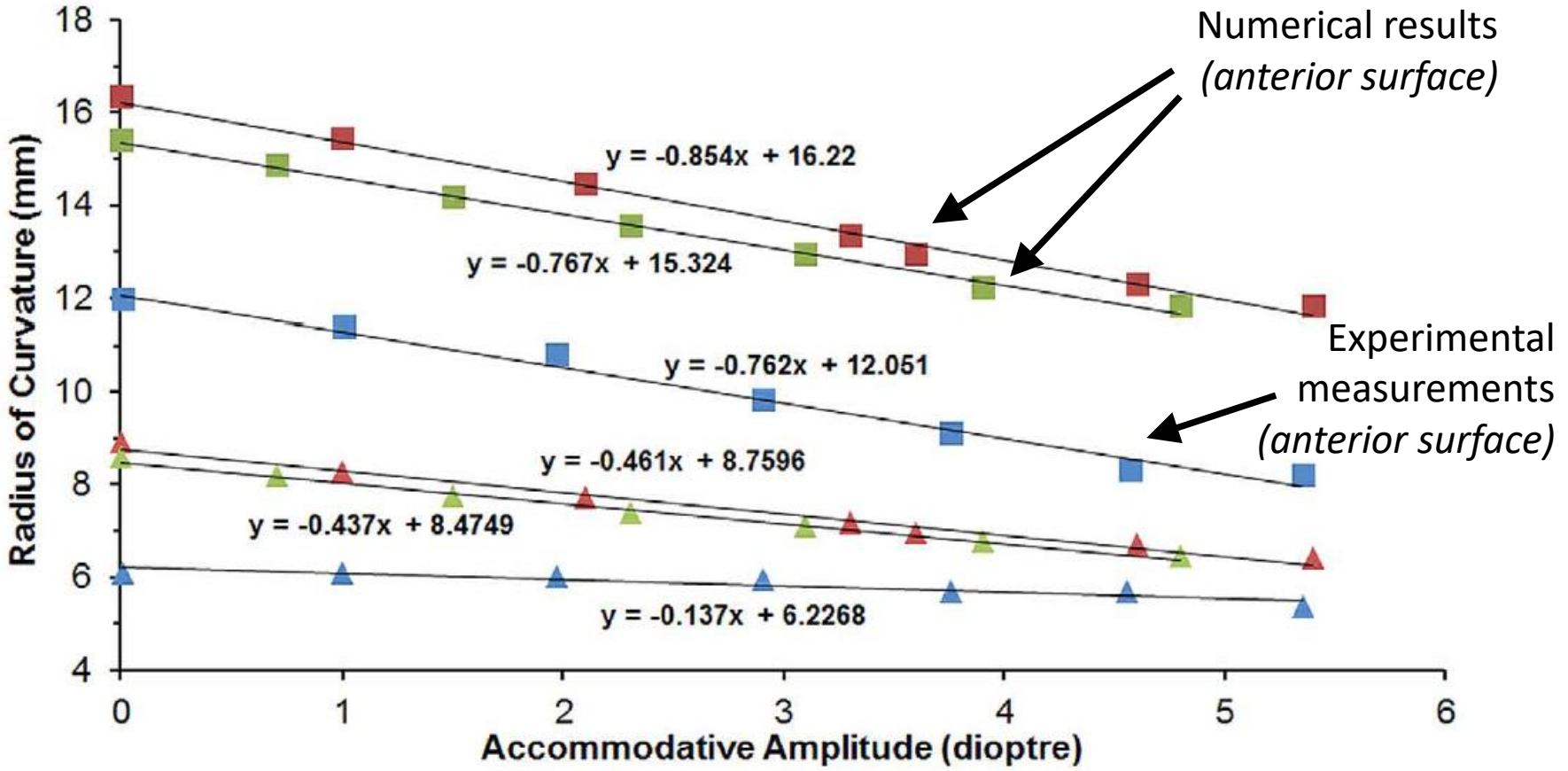
Wang K. et al, Sci Rep, 6, 2016.

Discontinuous stress field:

- ✓ Not a problem when examining the displacement field
- ✓ The displacement field is continuous
- ✓ The deformed shape can be considered as acceptable

Fitting to *in-vivo* data

- compared to a 29-year-old lens measured *in vivo*



Dubbelman M. et al, Vis Res, 2005.

Conclusions

- ✓ Equatorial zonule: less significant role on lens shape change than anterior & posterior zonular fibres
- ✓ Zonular angle triplets: those providing results more closely aligned to *in-vivo* data give lower accommodative amplitudes → zonular angles change with age and may account for the accommodative loss
- ✓ Capsular thickness should be taken into account in modelling (it affects optical performance of lens)
- ✓ A linear distribution of the modulus of elasticity could describe more accurately the stiffness tensor throughout the eye lens

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!! Thank you for your attention !!