Probabilistic Modeling of Intracranial Pressure Effects on Optic Nerve Biomechanics

C R. Ethier¹, Andrew J. Feola¹, Julia Raykin¹, Jerry G. Myers², Emily S. Nelson², Brian C. Samuels³

¹Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology and Emory University, ²NASA Glenn Research Center, Cleveland, Ohio, United States, ³Ophthalmology, UAB, Birmingham, Alabama, United States

Background and Purpose

- Altered intracranial pressure (ICP) is involved/implicated in several ocular conditions: papilledema, glaucoma and Visual Impairment and Intracranial Pressure (VIIP) syndrome
- ICP affects optic nerve head (ONH) biomechanics
- There are likely important inter-individual differences in biomechanical response to ICP, e.g. due to differences in ONH tissue properties.
- Goal: Quantify ICP-induced deformations of ONH tissues, using finite element (FE) and probabilistic modeling (Latin Hypercube Sampling (LHS)) to consider a range of tissue properties and relevant pressures

Methods: Finite Element Model

- Extend Sigal et al.’s (IOVS, 2005) model of the posterior eye/ONH
- Tissue constitutive models:
  - Neural tissue (prelaminar tissue, retina and optic nerve), lamina cribrosa and central retinal vessel treated as isotropic and linearly elastic
  - Sclera, dura mater and pia mater treated as Mooney-Rivlin material plus von Mises distributed fibers
  \[ \Psi = F_1(I_1, I_2) + \int_{\theta} P(\theta) F_2(\lambda(\theta))d\theta + \frac{K}{2} \ln(I)^2 \]

Methods: Latin Hypercube Sampling

- Simulate a virtual population: account for inter-individual variations in pressures and tissue mechanical properties
- IOP and MAP values taken from in-flight astronaut measurements.
- Three different ICP conditions considered: upright on earth (lowest), supine on earth (intermediate), elevated (presumed to occur in space).
- Tissue material properties: taken from literature and/or estimates
- Primary outcome measures: peak tensile and compressive strains in the prelaminar tissue, lamina cribrosa and retrolaminar optic nerve

What correlates with “extreme strains”?

- Divide virtual population into two groups: G1 and G2
- ICP significantly higher in G2
- Lower pia mater ground substance and fiber stiffness in G2
- Lower MAP and higher optic nerve compressibility in G2

Summary and Conclusions

- 47% of individuals experience “extreme strains” in the optic nerve
- c.f. 41% of astronauts suffering from VIIP syndrome
- Identified specific factors that are associated with these extreme strains
  - Elevated ICP
  - Weak pia mater
  - Lower MAP
  - Higher optic nerve compressibility
- Future experimental work should examine how/whether extreme strains contribute to pathophysiology of VIIP

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