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
  \[ \Psi = F_1(I_1, I_2) + \int_{\theta_0}^{\theta} P(\theta) F_2(\theta) d\theta + \frac{K}{2} \ln(\theta)^2 \]

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

Results: ONH Strains

- **1st Principal Strain (Tension):** ICP: 0 mmHg, 20 mmHg
- **3rd Principal Strain (Compression):** ICP: 0 mmHg, 20 mmHg

Increasing ICP led to elevated strains particularly in the post-laminar optic nerve

Results: Latin Hypercube Sampling

- **Lamina Cribrosa:**
  - Upright ICP: Peak Compression, Peak Tension
  - Supine ICP: Peak Compression, Peak Tension
  - Elevated ICP: Peak Compression, Peak Tension

- **Prelaminar neural tissue:**
  - Upright ICP: Peak Compression, Peak Tension
  - Supine ICP: Peak Compression, Peak Tension
  - Elevated ICP: Peak Compression, Peak Tension

- **Post-laminar nerve:**
  - Upright ICP: Peak Compression, Peak Tension
  - Supine ICP: Peak Compression, Peak Tension
  - Elevated ICP: Peak Compression, Peak Tension

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