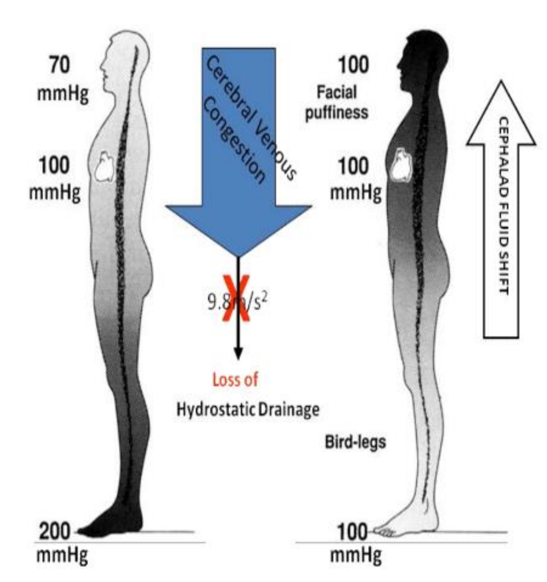
Optic Nerve Sheath Mechanics in VIIP Syndrome

Julia Raykin [1], Andrew Feola [1], Rudy Gleason [1], Lealem Mulugeta [2], Jerry Myers[3], Emily Nelson[3], Brian Samuels[4] and C. Ross Ethier[1]

[1]Department of Biomedical Engineering, Georgia Institute of Technology/Emory University, Atlanta, GA
[2]NASA Glenn Research Center, Cleveland, OH
[3]Universities Space Research Association, Houston, TX
[4]Department of Ophthalmology, U. Alabama at Birmingham, Birmingham, AL

BACKGROUND – VIIP Syndrome

Visual Impairment and Intracranial Pressure (VIIP) syndrome results in a loss of visual function and occurs in astronauts following long-duration spaceflight. Understanding the mechanisms that lead to the ocular changes involved in VIIP is of critical importance for space medicine research..



humanresearchroadmap.nasa.gov

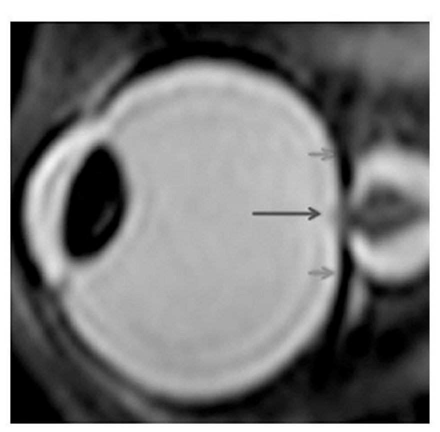
Cephalad fluid shift hypothesis

in microgravity, the pressure gradient in the body is significantly reduced, resulting in higher pressures in the head (increased intracranial pressures, ICP)

VIIP occurs in ~40% of US astronauts

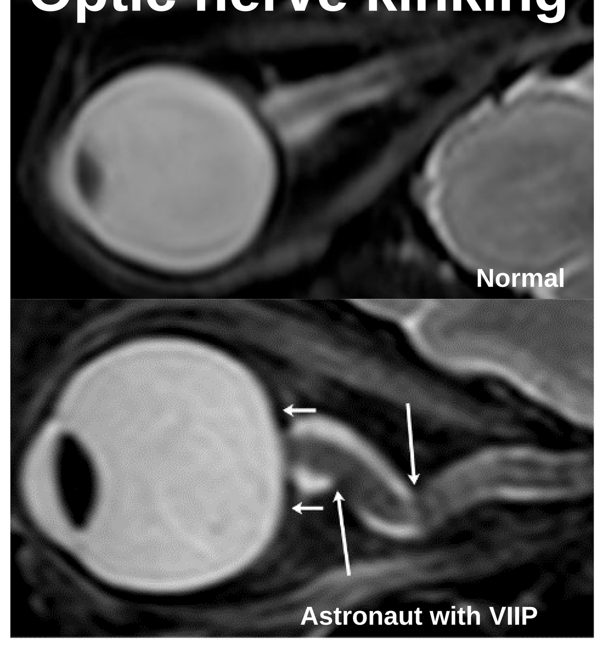
Some astronauts present with optic nerve distension and/or a kink in the optic nerve after return to earth strongly suggesting that axial distension and tissue remodeling in response to ICP increases may be taking place.

Optic nerve distension



Mader et al, Ophthamology, 2011

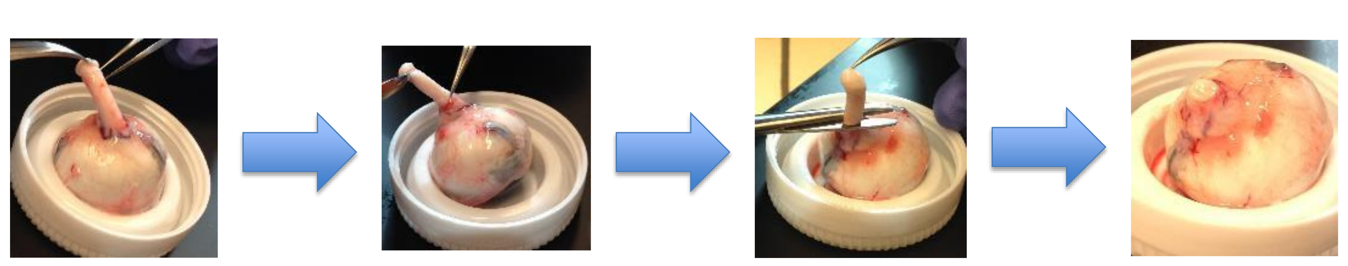
Optic nerve kinking



Kramer et al. Radiology, 2012.

The goal of this work is to characterize the mechanical properties of the optic nerve sheath (dura mater) to better understand its biomechanical response to increased ICP.

METHODS

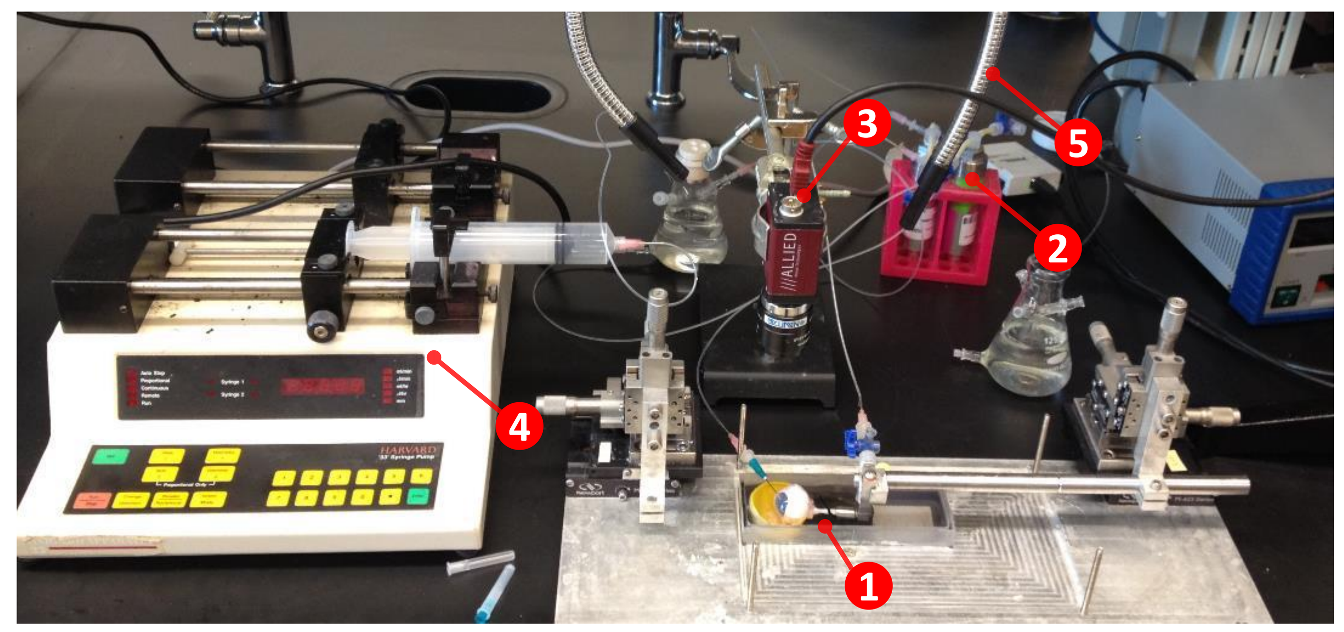


- Fresh porcine eyes obtained from local abattoir
- The optic nerve sheath was peeled away from the optic nerve proper then cut away from the globe and attached to a pressure control system (to simulate CSF pressure)

METHODS – Mechanical Testing

- CSF pressure was cycled between 0-60 mm Hg at different IOPs
- Axial stretch was controlled via micrometers
- Outer diameter of nerve sheath was recorded
- Axial force was measured with a force transducer

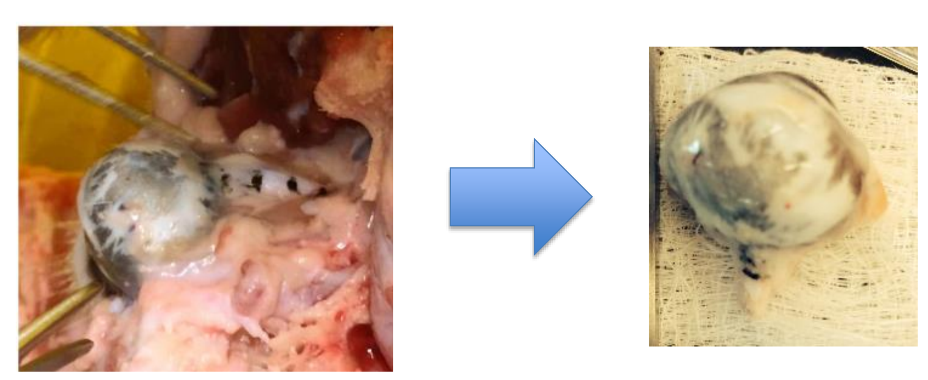
Mechanical Testing System



1 - Specimen bath/mounted porcine dura
2 - Pressure transducers
3 - CCD camera
4 - Syringe pump
5 - Light source

RESULTS

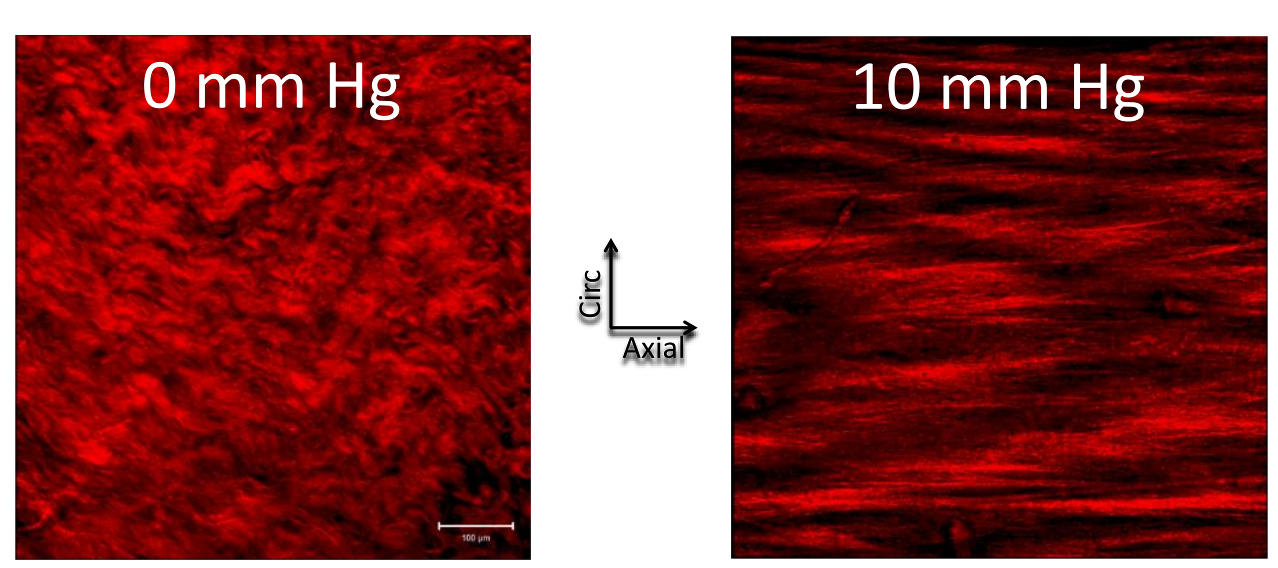
In vivo axial stretch measurements



$$\lambda_z = \frac{l}{L} \approx 2.0$$

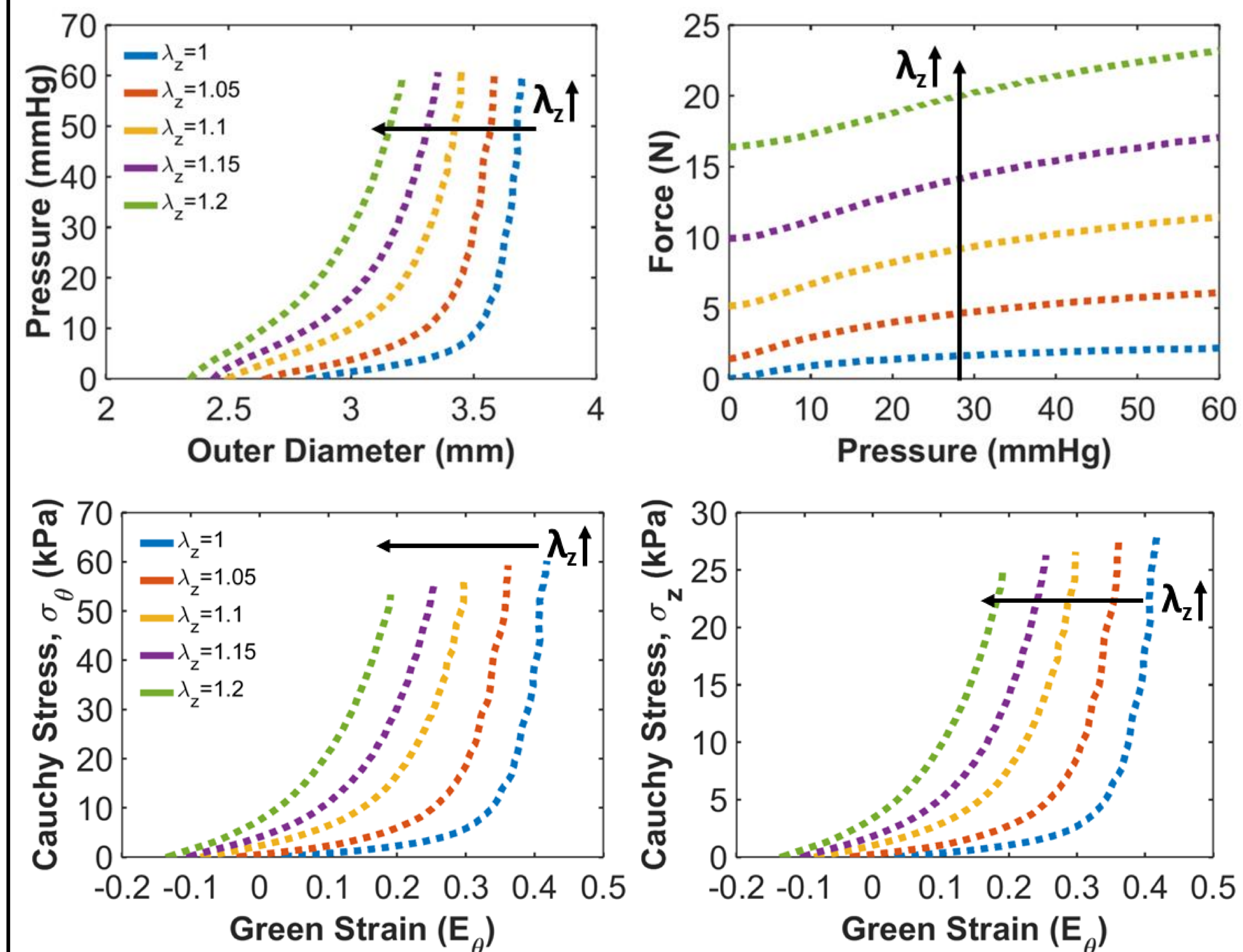
L:undeformed length
l:stretched length

Axial alignment of collagen fibers in the dura (Second Harmonic Generation)



RESULTS

Mechanical Properties



CONCLUSIONS

- Large in vivo axial stretch (~100%)
- Large deformations occur at pressures 0-10 mm Hg (~80%)
  - Consistent with changes seen in humans in response to increases in ICP
- High variability
  - Could be due to dura not being a load bearing structure, so the structural integrity is not preserved between samples
- High variation in mechanical properties could explain why some astronauts get VIIP whereas others do not
- Axial orientation of the collagen fibers and a lack of circumferential cross-fibers could lead to significant circumferential distension of the dura during increases in ICP
  - Remodeling would occur to lessen the tension and would result in the kink seen in astronauts with VIIP

Including these observations into computational models of the ONS will help improve their accuracy and enable prediction of possible risk factors of VIIP.

Funding: NASA grant number NNX13AP91G and NSBRI First Award Fellowship Program