Optic Nerve Sheath Mechanics and Permeability in VIIP Syndrome

Julia Raykin¹, Lauren Best², Rudy Gleason¹, Lealem Mulugeta³, Jerry Myers², Emily Nelson², Brian C. Samuels⁴ and C R. Ethier¹

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

• **N**: None of the authors have any commercial relationships
Visual Impairment and Intracranial Pressure Syndrome (VIIP)

• Altered visual function following long-duration space flights

• 41.7% incidence in the U.S.

• Physiological adaptations to microgravity

• Cephalad fluid shifts
Cephalad Fluid Shifts

1G
70 mmHg
100 mmHg

Cerebral Venous Congestion

0G
100 Facial puffiness
100 mmHg

Loss of Hydrostatic Drainage
Bird-legs

200 mmHg

9.8 m/s²

humanresearchroadmap.nasa.gov
Structural Changes in the Optic Nerve

Tortuous optic nerve observed in an astronaut with visual disturbances following long duration space flight. Taken from Kramer et al. Radiology, 2012.
• Goal: study the mechanical properties of the optic nerve sheath at various CSF pressures to understand visual disturbances that occur during long-term space travel

• Hypothesis: increased CSF pressure drives remodeling of the posterior eye and the optic nerve sheath
Optic Nerve: Anatomy


Experimental Protocol

1. Sheath is peeled away from the nerve proper

2. Nerve proper is cut away

3. The optic nerve sheath is cannulated and connected to a pressure control system
Experimental System

System Components:
1 - Specimen bath/mounted porcine eye
2 - Syringe pump
3 - Pressure transducers
4 - CCD camera
Pressure-Diameter Tests
Modulus Increases at Higher Pressures

\[ \varepsilon = \frac{r}{r_o} - 1 \quad \sigma = \frac{Pr}{h} \]
Collagen Fiber Orientation
Collagen Orientation Changes with Distance from the Globe
Collagen Fiber Undulation
Collagen Fiber Undulation

% Engagement = \( \frac{T}{C} \cdot 100 \)

Collagen Structure

Optic Nerve Sheath

Arterial Adventitia

Blood Vessel Behavior

- Remodel in response to high pressures
- Wall thickens to reduce stress on cells

\[ \sigma = \frac{Pr}{h} \]

- Appear to remodel towards target stresses
Permeability-Experimental Setup
Permeability-Results

\[ K = \frac{V}{P \cdot A \cdot t} \]

- V: outflow volume (µL)
- P: pressure (mm Hg)
- A: optic nerve surface area (cm²)
- t: time (s)

Estimation for Humans:

\[ Outflow \ Rate = K \cdot P \cdot A = 125 \ \text{mL/day} \text{ at 7 mm Hg} \]

20% of daily CSF production

Summary

• Optic nerve sheath exhibits typical soft tissue behavior:
  – Preconditioning effect in the early cycles of cyclic pressure diameter testing
  – Repeatable behavior following the fourth pressure-diameter cycle
  – Nonlinear stiffening at pressures
  – Anistropic behavior due to collagen orientation

• Structure and behavior appears to be similar to the adventitia

• High permeability suggests CSF drainage could play an important role in VIIP syndrome
Limitations

• Peeling away the meninges could cause structural damage

• Lack of availability of long human optic nerves

• Post mortem effects on permeability
Future Directions

• Quantify microstructural changes during mechanical loading

• Incorporate results into computational models of VIIP syndrome
  – Help identify possible interventions
Acknowledgements

Funding
NASA grant number NNX13AP91G

DeVon Griffin