NASA’s Visual Impairment & Intracranial Pressure Risk: Utilizing the ISS for Risk Reduction

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VIIP Clinical Findings

• To date 15 U.S. ISS long-duration spaceflight astronauts have developed some or all of the following findings:
  
  - Hyperopic shift
  - Choroidal folds
  - Cotton wool spots
  - Optic Nerve Sheath Distention
  - Globe flattening
  - Edema of the Optic disc (papilledema)

  Signs of elevated intracranial pressure

• High postflight intracranial pressure in four crew members:
  
  - 15.4-21.3mmHg (Normal: 7-15mmHg) or,
  - 21-29 cmH2O, Normal: 9.5-20.4cmH2O
Initial Identification of the VIIP: Subjective Changes in Vision

- 50% of long-duration (ISS) mission astronauts report a subjective degradation in vision, primarily increasing *farsightedness*

- **Hyperopic shift**

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**Decreased near visual acuity, distant vision intact**

(1 mm decrease in axial length is equivalent to a 3 diaper hyperopic shift)
Pre to Post Flight Papilledema: A Clinical Sign of Raised Intracranial Pressure

**Pre Flight**
Fundoscopic images of the right and left optic disc.

**Post Flight**
Fundoscopic images of the right and left optic disc showing **Grade 3 edema right** and **Grade 1 edema left**.
In Flight B-scan Ultrasound
ISS Inflight Crew Ultrasound Imaging: Additional Signs of Raised Intracranial Pressure

1. Increased Optic Nerve Sheath Diameter

   Terrestrial Normal ≤ 5.9 mm

2. Posterior Globe Flattening

   Flattening of Posterior Globe

3. Raised Optic Disc

   Postflight
Choroidal Folds

Thickening of the choroid secondary to venous blood engorgement from uG fluid shift
Case Classification (U.S. ISS Crew) (As of Jan 2012)

- 36 U.S. ISS crew flown to date:
  - Confirmed non-cases N=5
  - Unclassified crew N=16
    - CPG Class One N=2
    - CPG Class Two N=8
    - CPG Class Three N=1
    - CPG Class Four N=4

    30% Class 1&2
    15% Class 3&4

**Current VIIP Incidence in U.S. crew = 41.7%**

- **Potential long-term changes:**
  - Decreased near visual acuity
  - Peripheral vision loss
  - Neurocognitive changes

- **Higher risk likely on longer exploration missions** (*dose-response*)
Piecing Together Visual Impairment and Elevated Intracranial Pressure in Spaceflight

A Three-Part Story

1. The Vascular System

2. The Brain

3. The Eye
Loss of Hydrostatic Drainage & Cerebral Venous Congestion

Adapted from Rowell, 1988

1G

70

100

200

Cerebral Venous Congestion

9.8 m/s²

Loss of Hydrostatic Drainage

1G Supine

0G

100 Facial puffiness

100

Bird-legs

Adapted from Hargens & Richardson, Respiratory Physiology & Neurobiology. 2009

Adapted from Rowell, 1988


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**Tilt Angle vs ICP & CVP: Positional Fluid Shifts**

- ICP 24 mmHg
- CVP = 9 mmHg

- ICP 9.6 mmHg
- CVP = 5 mmHg

- ICP -1.8 mmHg
- CVP = 0 mmHg

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Converted to mmHg
Accommodation of up to 120ml volume change while maintaining normal ICP
Fluid Shift & Inadequate Cerebral Venous & CSF Accommodation May Increase ICP in 0G

0G Cephalad fluid shift causes venous blood & CSF outflow resistance
## Occupational Data Mining in ISS Crew: Cardiovascular Variables

<table>
<thead>
<tr>
<th>Cardiovascular Variable</th>
<th>Significant Correlation Across CPG Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biochemistry:</strong></td>
<td></td>
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<tr>
<td>LDL</td>
<td>√</td>
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<tr>
<td>HDL</td>
<td>-</td>
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<tr>
<td>Triglycerides</td>
<td>-</td>
</tr>
<tr>
<td>Hemoglobin A1c</td>
<td>√</td>
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<tr>
<td>Fasting serum glucose</td>
<td>√</td>
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<tr>
<td>Homocysteine</td>
<td>√</td>
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<tr>
<td><strong>Body Composition:</strong></td>
<td></td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>√</td>
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<tr>
<td>Percentage Body Fat</td>
<td>√</td>
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<tr>
<td><strong>Cardiac:</strong></td>
<td></td>
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<tr>
<td>Resting blood pressure (pre-in-post flight)</td>
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<tr>
<td>Pulse Pressure (pre-in-post flight)</td>
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<tr>
<td>CT Coronary Calcium Score</td>
<td>-</td>
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<tr>
<td><strong>Aerobic Capacity:</strong></td>
<td></td>
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<tr>
<td>Decreased Maximal Oxygen Uptake</td>
<td>√</td>
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</tbody>
</table>

All correlated factors adversely affect vascular structure & function.
## Ocular Variables

<table>
<thead>
<tr>
<th>Ocular Variable</th>
<th>Significant Correlation across CPG Classification</th>
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<tbody>
<tr>
<td><strong>Eye Findings:</strong></td>
<td></td>
</tr>
<tr>
<td>Refractive vision change</td>
<td>√</td>
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<tr>
<td>Retinal Nerve Fiber Layer</td>
<td>√</td>
</tr>
<tr>
<td>Optic Nerve Sheath Diameter</td>
<td>√</td>
</tr>
<tr>
<td>Intraocular Pressure</td>
<td>√</td>
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</tbody>
</table>
A Working Model: Potential Interaction of the CNS, Vascular, & Ocular System in the VIIP

Hydrostatic Drainage
Loss of Cerebral Venous Blood
Cerebral Venous Congestion

Adapted from Rekate
Impact of Inflight Exacerbating Factors?

Resistive Exercise
Does in-flight resistance training cause additional transient elevations in ICP?

High Oral Sodium Intake
Prepackaged Foods
High in sodium
Up to 5000mg+ per day

Inflight Pharmaceuticals
Effects on VIIP?
CO₂ Levels on ISS

- CO₂ is an extremely potent vasodilator
  - Every 1mmHg increase PaCO₂=4% increase in dilation

- CO₂ mission average=3.56mmHg (0.33%)
  - 10x normal sea level atmospheric: 0.0314%
  - Average Peak CO₂=8.32mmHg (0.7%) (20x)

- CO₂ also causes increased CSF production due to increased flux of HCO₃⁻ across choroid plexus & accompanying H₂O

Adapted from Alperin et al. Radiology, 2000
ISS In-flight Ocular Study

Preflight Exams
- L-21/18 mo
- L-12/9 mo
- L-6/3 mo
- MRI Of Brain and Orbits Without Contrast
- Ultrasound Eye/Orbit
- Fundoscopy
- Tonometry
- Visual Acuity Including Questionnaire & Amsler Grid Testing
- Other Tests - biomicroscopy (slit lamp), high resolution retinal photography, OCT (high resolution), and A-Scan.

In-flight Exams
- L+30, R-30 & as clinically indicated
- Ultrasound Eye/Orbit
- Fundoscopy
- Tonometry
- Visual Acuity Including Questionnaire & Amsler Grid Testing
- Vascular Compliance With Blood Pressure
- L+100

Post flight Exams
- R+1/3
- R+30
- R+90
- R+180
- R+365
- MRI Of Brain and Orbits Without Contrast
- Ultrasound Eye/Orbit
- Fundoscopy
- Tonometry
- Blood Pressure
- Visual Acuity Including Questionnaire & Amsler Grid Testing
- Other visual tests
- Vascular Compliance With Blood Pressure
- Other Tests - biomicroscopy (slit lamp), high resolution retinal photography, OCT (high resolution), and A-Scan.
ISS In-flight Studies: Braslet Occlusion Cuff

Sequesters venous blood in the legs

No Braslet

<table>
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<tr>
<th>Leg</th>
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<tr>
<td>Femoral Vein</td>
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Braslet

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Duncan et al. NASA SDTO 17011
Russian Chibis LBNP Device
(Negative Pressure)

Components:
- Chibis suit (ПВК-1)
- Chibis suit pressure control unit (ПВК-Д)
- Hose harness in kit
- ПВК-1 removable waist seal curtain in kit

Removable waist seal curtain
Drum
Corrugated sheath
Belt
Shoulder straps with clasps
ПВК-Д unit control handle
Hose harness
Rigid boots

Chibis Suit (ПВК-1)
Non-Invasive Intracranial Pressure Measurement

Vittamed 205 Monitor

Cochlear and Cerebral Fluid Pressure (CCFP) Analyzer
VIIP Knowledge & Technology Transfer to Terrestrial Medicine

- VIIP risk has brought together leading authorities in neurology, neurosurgery & ophthalmology
- The VIIP syndrome is challenging them to view their own area of expertise from a unique perspective
- The NASA VIIP team continues to disseminate advances in understanding the VIIP syndrome with the clinical community:
  - E.g. CSF Symposium, John’s Hopkins, UT Optometry
- Improved understanding of glaucoma
- Improved diagnosis & treatment of Idiopathic Intracranial Hypertension
- Technology transfer to terrestrial medicine:
  - Assessment of Intracranial pressure using novel techniques & new protocols
  - New remote guidance techniques
  - Advancing telemedicine using standard clinical tools
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Common Characteristics of the Cases

- Approximately 6 month duration ISS mission
- All had normal preflight eye examinations
- Past medical history was negative for systemic disease; and none had used medications before or during their mission that could increase ICP (e.g., vitamin A, tetracycline, corticosteroids, or nalidixic acid)
Redistribution of Venous Pressures
From 1G to 0G

Cranium is rigid
Venous congestion
Obligate arterial flow
Transcapillary leak
++ICP~30-40