Testing Mechanical Countermeasures to Cephalad Fluid Shifts

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INTRODUCTION
Over the past several years, clinical observations by NASA have revealed evidence suggesting intracranial pressure (ICP) is elevated in astronauts. Visual signs predominate, including globe flattening, disc edema, and choroidal folds. In a few cases, clinically relevant visual symptoms have persisted over 3 years, and in a handful of astronauts elevated ICP has been found days or months post-flight (measured by lumbar puncture). This visual impairment and intracranial pressure (VIIIP) condition varies notably across astronauts. Contributing factors are poorly understood, but globe flattening, plus few if any changes in IOP, suggest ICP elevation.

While the evidence for elevated ICP remains circumstantial and the etiology remains unknown, the VIIIP risk is of sufficiently high priority—and the circumstantial evidence is sufficiently strong—that investigations of countermeasures for elevated ICP appear warranted. To date, no countermeasures have been tested for VIIIP, although two countermeasures have been utilized in spaceflight to mitigate in-flight cephalad fluid shifts (and related cardiovascular changes): (1) Russian-made Braslet thigh cuffs, and (2) lower-body negative pressure (LBNP). Both help redistribute blood from the upper body into the lower extremities, for a more Earth-equivalent fluid distribution. Both have operational challenges, including availability, obtrusiveness, and calibration.

MAIN PROJECT AIMS
1. Identify and characterize cerebrovascular and/or ophthalmological parameters altered by cephalad fluid shifts. Determine whether these effects can be mitigated by either of two mechanical countermeasures (CMs).
2. Identify any rebound/adverse events following CM discontinuation, and determine if gradual CM discontinuation is safer than abrupt discontinuation.
3. Assess the relationship between CM exposure time vs. ICP reduction (and associated rebound effects).

METHODS
We are adapting and investigating 2 commercially-available systems for their potential to reduce elevated ICP. These include (1) the Kaatsu System, and (2) the LymphaPress system.

Kaatsu
- Inflatable cuffs worn around legs or arms
- Similar to Braslet
- Designed for hypoxic strength training
- We are developing protocols for leg cuff use as a more finely controllable Braslet-type device.

LymphaPress
- Air bladders compress fluids from distal legs towards the abdomen.
- Designed for patients with lymphedema.
- We are modifying the system & deployment protocol to compress fluids towards the distal legs.

INITIAL PROGRESS
Pilot testing with modified devices & protocols has identified consistent mitigation of ↑CBV with both systems.

Kaatsu
- Figure 1: CBV (total [Hb]) increased with HDT, even with Kaatsu inflated. The increase was enhanced when Kaatsu was released. Re-inflation during HDT had little effect, but subsequent mild exercise reduced CBV. Release of Kaatsu again increased CBV. Return to supine brought CBV towards baseline.

LymphaPress
- Figure 2: CBV (total [Hb]) again increased with HDT (while wearing uninflated LymphaPants). Peristaltic inflation cycles led to temporary decreases in HBT. During deflation of the LymphaPants, HBT returned to the increased HBT level. Return to supine posture brought CBV back to baseline.

PLANNED TESTING PROTOCOL
Subjects: (1) NeuroICU patients with invasive ICP sensor, (2) Healthy subjects undergoing acute -10g HDT
Protocols: (1) 15-min tests for feasibility and initial efficacy, (2) gradual vs. more abrupt discontinuation, and (3) evaluate duration-of-application effects.
Measures: invasive ICP, Vittamed ICP, NIRS (CBV & Hb), tissue oximetry, BP, TCD, 3D ocular US, IOP, IVC.

DISCUSSION
- Device and protocol adaptation has been more challenging and time-consuming than anticipated.
- Pilot data suggests Kaatsu & LymphaPress both have potential to alter cephalad fluids. Effects on ICP will be determined in the patient studies.
- Both Kaatsu & LymphaPress exhibit post-release physiological changes. These need to be characterized.

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