REPLY TO LUDWIG ET AL.:

A potential mechanism for intracranial cerebrospinal fluid accumulation during long-duration spaceflight

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We thank Ludwig et al. for their interest in our work (1) and for bringing a revealing aspect of cerebrospinal fluid (CSF) dynamics to our attention (2). The flow reversal of the internal CSF circulation during forced breathing maneuvers in interrelation with cranial and thoracic venous vasculature responses demonstrated by their research group may in fact be part of a general mechanism that we aim to confirm to be at the core of our findings and other cranial changes observed during and after long-duration spaceflight (3–5). This presumed mechanism is a profound reduction of the bulk flow from CSF space into the dural veins in microgravity compared to conditions here on Earth.

Lawley et al. (6) demonstrated in-depth that the intracranial pressure as measured in ventricular CSF space via an implanted Ommaya reservoir is reduced upon entering a zero-gravity environment during parabolic flight while arterial blood pressure remains unchanged. At the same time, they showed a substantial increase in jugular vein diameter in microgravity and predicted an increase in dural sinus pressure of almost 3 mmHg. Most long-duration space travelers experience puffy faces as well as nasal congestion, both of which resemble pooling of venous blood in the head as part of the so-called cephalad fluid shift. Entering these facts—reduced intracranial pressure with unaffected arterial blood pressure leading to an unchanged CSF secretion while cephalic venous pressure, especially at the most cranial locations (and in the absence of backflow-protecting valves in the cerebral veins), is slightly but permanently increased in microgravity—into Davson et al.'s (7) equation results in a reduction of CSF absorption capacity or relative overproduction of CSF. We hypothesize this minimal but lasting change in volume transfer gradient from CSF space into the cranial venous vasculature over the longer mission durations (>6 wk) aboard the International Space Station (ISS) to lead to the intracranial fluid accumulation which we observed. The slowness of this process in our opinion is reflected in the nonreporting of severe headaches or a pulsatile tinnitus by the long-duration space travelers as well as in the delayed onset of Spaceflight-Associated Neuro-ocular Syndrome (SANS) after 6 to 8 wk and the gradual increase of head temperature potentially due to cranial venous congestion from weeks 2 through 10 (8, 9).

At present the only viable countermeasure in the absence of artificial gravity aboard the ISS seems to be lower-body negative-pressure suits to reduce cephalic blood pooling (10). It is used by the cosmonauts only toward the end of a mission for now (11).

On a separate note we have to disagree with Ludwig et al. (2) for using the term "disease" in the context of our and other medical findings after long-duration spaceflight at this point in time. We would consider this research to be still at a syndromal stage of gathering neuroradiological results in the absence of known persistent (>2 wk) neurological symptoms in microgravity and after return to Earth aside from the SANS. Comprehensive long-term follow-up studies will hopefully clarify this issue in the future.

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