Ultimate Ultrasound Challenge: "Houston, we have a problem!"

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Space adaptation syndrome and visual impairment with increased intracranial pressure (ICP) remain a puzzling problem of astronauts' health and missions. These changes define the visual impairment/intracranial pressure (VIIP) syndrome. There are limited pre- and postflight measures to define the risk and even less inflight data is available. The goal of this study was to use multi-equipment ultrasound protocol simultaneously (patent pending) to measure intracranial and extracranial flow patterns (carotid duplex) before an astronaut's mission to established baseline data that could provide important information about flow patterns during ICP with and without gravity.

BACKGROUND

Over the last 40 years there have been reports of visual impairments associated with spaceflight through testing and anecdotal reports.These changes were thought to be transient, but a comparison of pre and post flight ocular measures have identified a potential risk of permanent visual changes as a result of microgravity exposure. Various examinations reported an experience of visual performance decrements, cotton-wool spot formation, choroidal fold development, optic-disc edema, optic nerve sheath distention, and/or posterior globe flattening with varying degrees of severity and permanence in subsets of crewmembers. These changes define the visual impairment/intracranial pressure (VIIP) syndrome.

It is thought that the ocular structural and optic nerve changes are caused by events precipitated by the cephalad-fluid shift crewmembers experience during long-duration spaceflights (more than 5 months), these changes have not been noticed or could be asymptomatic during short shuttle missions (less than 2 weeks). We have a small sample group but as of today 15 astronauts have been diagnosed with VIIP. It is not an "American" phenomenon, Russians also reported it in 2001.

The first documented case of a U.S. astronaut affected by the VIIP syndrome occurred in an astronaut during a long-duration International Space Station (ISS) mission in 2005. "The astronaut noticed a marked decrease in near-visual acuity throughout the mission. This individual's postflight fundoscopic examination and fluorescence angiography revealed choroidal folds inferior to the optic disc and a cotton-wool spot in the right eye, with no evidence of optic-disc edema in either eye. The left eye examination was normal. The acquired choroidal folds gradually improved but were still present 3 years postflight. Brain MRI, lumbar puncture, and OCT were not performed preflight or postflight on this astronaut."

It is believed that some crewmembers are more susceptible due to genetic/anatomical predisposition or lifestyle (fitness) related factors. Previous mission also became a risk factor. Three important systems – ocular, cardiovascular, and central nervous – will be evaluated to understand the risk of developing the VIIP syndrome. Several hypotheses have been proposed to explain the identified visual acuity and structural changes including increased intracranial pressure, localized ocular changes such as ocular hypotony, decreased venous compliance, and alterations in cerebrospinal fluid dynamics.

There are limited pre- and postflight measures to define the risk and even less in-flight data is available, but cardiovascular risk factor assessments failed to utilize a non-invasive brain flow testing which has a potential value to predict or screen ICP.

OBJECTIVES

It has been hypothesized that venous congestion in the brain and/or eye, brought about by cephalad-fluid shifts (2L fluid lost from legs causing puffy face/edema), could be tested with a simple carotid duplex examination of the neck/head venous system. Transcranial Doppler (TCD) is an ultrasound test of the brain circulation and it is an operator-dependent technique for measuring cerebral blood flow changes. The goal of this study was to use multi-equipment ultrasound protocol simultaneously (patent pending) to measure intracranial and extracranial flow patterns (carotid duplex) before an astronaut's mission to established baseline data that could provide important information about flow patterns during ICP with and without gravity.

METHODS

We studied a 49-year-old male astronaut using simultaneous bilateral transcranial Doppler (TCD) monitoring and bilateral carotid duplex ultrasound in 5 different body positions: 1) standing, 2) sitting, 3) lying flat, 4) -15° head down, and 5) -30° head down, during 3 different breathing exercises: normo-, hyper- and hypoventilation, 2 months prior to his mission. Using remote-guided, "zero" gravity TCD ultrasound, the 3 different breathing exercises were repeated during the Mission for comparison. Changes beyond 30% of acceptable ranges were considered significant.

RESULTS

Continuous digital recordings were analyzed and data (in thirty-second intervals) were entered into a database. During normoventilation (Table 1-2), no significant velocity (V, 29%) changes were observed in the right posterior cerebral artery (RtPCA) or in the left middle cerebral artery (LtMCA, 13%). Significant changes in velocity and pulsatility index (PI) were observed during both hyperventilation (RtPCA V, 71%; LtMCA V, 71%; RtPCA PI, 38%; LtMCA PI, 47%) (Table 3-4) and hypoventilation (RtPCA V, 37%; LtMCA V, 60%; RtPCA PI, 67%; LtMCA PI, 54%) (Table 4-6), which corrected by autoregulation within 30 seconds.

PI value changes clearly show the power of the intact autoregulation keeping MFV values stable. Similar V and PI changes were observed during "zero" gravity TCD examination without any signs of increased ICP.

Carotid duplex reported that Jugular vein (JV) diameter changed with body position; however, common carotid artery (CCA) diameter remained unchanged. [JV(cm)/CCA(cm): (1) 0.2 x 0.8/0.6 x 0.7; (2)0.3 x 1.4/0.6 x 0.9; (3)0.8 x 1.5/0.5 x 0.6; (4) 1.3 x 1.8/0.6 x 0.6; (5) 1.2 x 1.7/0.5 x 0.5] This indicates the JV becomes the major outflow for cerebral flow in head down positions.

CONCLUSION

Simultaneous, multi-equipment ultrasound testing could be helpful to study cerebral autoregulation and the connection between extra/intracranial flow, as well as arterial/venous flow patterns with and without gravity in cerebrovascular syndromes. VIIP syndrome remains a puzzling problem of astronauts` health and it prevents the planning of longer missions to explore our boundaries in the universe.

Further validations are necessary. These observations are also relevant for medical conditions with ICP on Earth. TCD is already a useful tool in detecting vasospasm and occlusion in our every day practices but there is still room for improvement when dealing with unrecognized and underdetected ischemia and hypoperfusion after stroke, intracerebral or subarachnoid, and cerebellar hemorrhages. The danger of intracranial hypertension is frequently underestimated, especially in stroke patients. In many cases, ICP is not monitored, and it may cause severe secondary insults by unrecognized ICP elevation. Therefore, non invasive ICP assessment tools and methods developed for NASA could be a helpful tool for our patients, too.

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