Human Adaptation to Space: Space Physiology and Countermeasures

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Humans engaged in space flight respond to more than just the microgravity environment. They also respond to acceleration impacts, living and working in confined spaces, remote deployment, restricted communication, limited privacy, demanding timelines, critical operations, and little or no availability of evacuation. All of this contributes to physiological, mental, and emotional stress. NASA flies sundry types of missions with a diverse corps of astronauts, each of whom responds differently to the stressors to which he or she is exposed. So in our planning, we must consider the likelihood and consequences of health and performance risks, alterations in acute health, performance, and long-term health in the context of mission objectives.

Astronauts adapt to microgravity within the first few days of exposure. The space adaptation process, common to both short- and long-duration missions, is less noticeable in the context of a long-duration mission because it takes up a much smaller portion of the overall mission time (~22% of short-duration and ~1.5% of long-duration missions). In light of this, how do we prioritize risks and risk factors to address differing mission lengths?

To make well-informed decisions, NASA invests in measuring and understanding a number of physiological systems. This is because it is at the level of these systems, and the risk factors manifested within them, that we can successfully intervene and perhaps minimize the likelihood and/or consequence of a risk. Conditions common to short-duration flight include: space motion sickness, headache, back pain, insomnia, nasal congestion, constipation, nosebleeds, urinary retention, and incontinence. These conditions, as a group, are known as space adaptation syndrome.

Space adaptation syndrome manifests early in space flight (within minutes or hours) and can last 72 hours or longer. A tremendous amount of individual variability exists with regard to the intensity and duration of its symptoms and conditions, however. We know, for example, that astronauts who flew on more than one mission experienced a different adaptation process for each mission. It is thus difficult to predict what an individual will experience in adapting to space. This inability to predict intensity and duration challenges us in terms of supplying appropriate therapies, including prophylaxis. Therefore, we need to cultivate an understanding of the mechanisms behind these responses to be better prepared with regard to resources, and to leverage terrestrial medicine and try different and perhaps more effective solutions without introducing new risks via side effects or contraindications.

The concern with crews engaged in long-duration missions is not just space adaptation, but continued degradation of physiological systems and manifestation of disease over time. To date, we regularly analyze data on 20 long-duration International Space Station (ISS) astronauts (through Expedition 16) who have spent an average of 4 to 6 months in space. But if a future Exploration mission lasted 9 or 12 months, would the documented trends continue in a linear fashion? Are the decrements reversible once an astronaut returns to Earth?

We currently collect data on bone mineral density, aerobic capacity, neurovestibular organs, and performance changes. We are also using a three-device countermeasure system on the ISS to address the physiological effects of space flight. Each of these is discussed below.

Space medicine practitioners measure bone mineral density to document bone loss conferred by space flight. The imaging methodology in use today provides a two-dimensional (2D) measurement of bone mineral density. Because we now know, based on results of a published research study, that the three-dimensional (3D) architecture of the bone is altered in space flight, we are unsure of the degree of alteration and the consequence to bone strength. We thus need to develop an in-flight imaging solution to help us understand the 3D structure of bone to assess alterations in bone strength; this tool would need to be small, light, and lean (figure 1).

In addition to bone mineral density, we also measure aerobic capacity pre-flight, in flight (every 30 days), and post-flight to provide an index of the detraining effect of microgravity. These measurements show that: in flight, a precipitous decline occurs in aerobic capacity immediately; a small recovery takes place during the second and third month and then plateaus; and a noticeable decrement occurs immediately post-flight, 4 to 7 days after landing. We hypothesize that loss of muscle mass, redistribution of fluids, and alterations in the sensorimotor capability

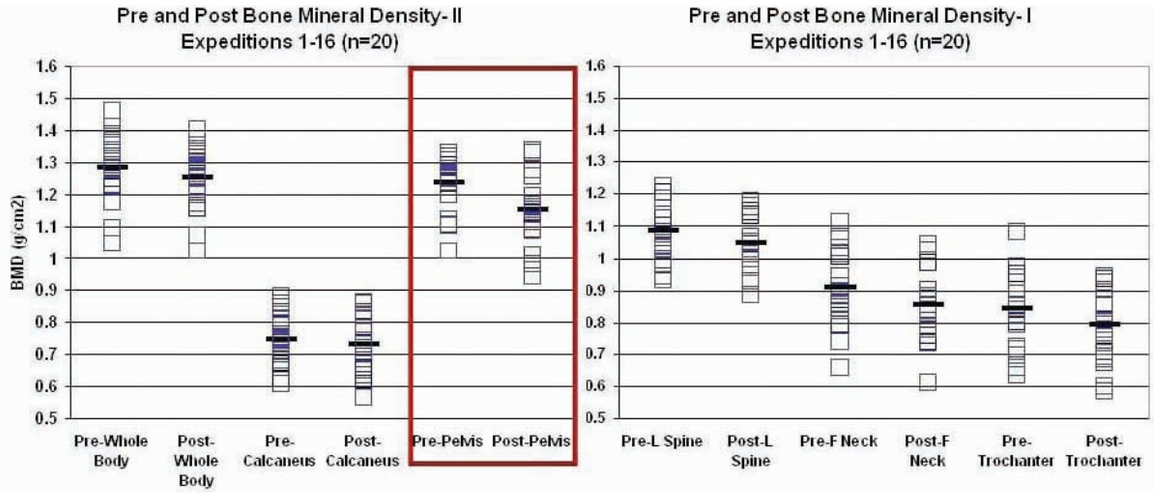

Fig. 1. *Pre and post bone mineral densities.*

lead, in concert, to reduced aerobic capacity post-flight. Fortunately, by 1 month after return, most astronauts have returned to their baseline or better. Yet although functional capacity is regained, it is unclear whether structural changes to the involved systems may persist (figure 2).

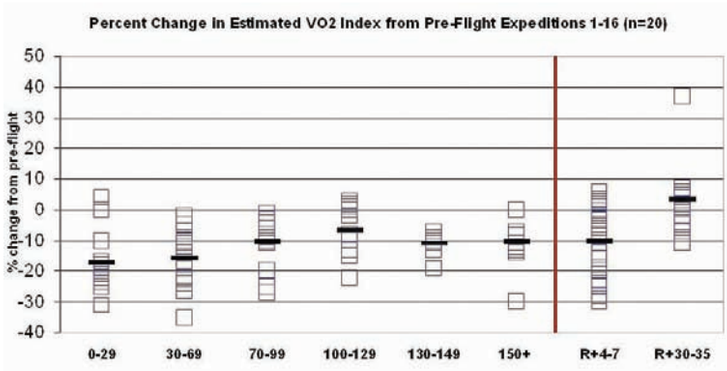

Fig. 2. *Percent change in estimated oxygen uptake (VO_2) index.*

Scientists have established that neurovestibular organs are affected by space flight, but it is often hard to determine the relative contribution of a cardiovascular effect and a neurological effect when a post-flight crew member is unable to remain upright. The sensorimotor test has proven effective for performing this assessment. We have therefore found that neurovestibular function returns post-flight, but not as quickly as cardiovascular function.

To assess performance impacts it is necessary to have specific information strength, flexibility, and core stability. Functional fitness data demonstrate that upper and lower body strength are diminished. A decrement is measured immediately post-flight. Fortunately, crew members do regain all functional fitness capabilities, often surpassing their pre-flight baseline.

A three-device countermeasure system (the resistive exercise device, treadmill, and cycle ergometer) is used on ISS to address the physiological effects of space flight. This integrated system supports crew capability for normal and contingency operations with limited redundancy and crossover. Ground crews, flight surgeons, and astronaut strength and conditioning specialists monitor crew data and adjust exercise programs accordingly. They also track the availability and reliability of the hardware to assess the equipment and determine whether it is meeting the needs of crew members, requires repair, and/or needs to be replaced.

To summarize, it is essential to use both current space flight missions and analog environments to study the effects of the stressors (e.g., acceleration, vibration, microgravity, fractional gravity) that we are placing on humans. Our ability to understand these effects at a fundamental and mechanistic level will allow us to better target countermeasure development, design selection criteria, and build medical kits to address conditions that we cannot prevent.

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