Human Spaceflight Ethics and Obligations:
Options for Monitoring, Diagnosing and Treating Former Astronauts
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INTRODUCTION

The Association of Space Explorers is an international nonprofit professional and educational organization that has only one prerequisite for membership – having made at least one orbit of the Earth in space. It was founded in 1985 by a small group of fliers from the U.S., the Soviet Union and other countries. Our vision is a world where living, working, and exploring in space will be as familiar to humanity as life on our home planet. We apply the unique perspective of our membership to promote the global benefits of space science, exploration and international cooperation; to educate and inspire future generations; and to foster better stewardship of our home planet. We count among our members over 400 current and former astronauts and cosmonauts from 37 nations, and are organized into four regional chapters - Russia, Europe, Asia, and ASE-USA. The latter is by far the largest, with 214 living members.

BACKGROUND

There is no doubt that human spaceflight is a risky endeavor. Statistical analysis shows that astronauts who fly to and from the ISS aboard a Soyuz spacecraft and spend six months there have a threat of mortality comparable to those of U.S. infantry combatants on D-Day and New York City firefighters on 9/11. Americans engaged in other dangerous professions, such as crop dusting pilots, timber cutters, construction workers and coal miners, are at least an order of magnitude less likely to lose their lives on the job.

The greatest risk during spaceflight is incurred during the dynamic phases of launch and reentry. Massive amounts of energy are focused to propel the spacecraft in the intended direction during launch and insertion, and the same energy must later be carefully and precisely shed for deorbit and landing. NASA spends significant resources to understand and mitigate the risks associated with these stages of flight, as well as to grapple with the primary peril once in orbit – an encounter with micrometeoroid orbital debris. As more experience is accrued, lessons are learned and the effectiveness in managing those risks increases.

PROBLEM STATEMENT

The impact of exposure to health hazards in the unique environment of spaceflight is a far less understood danger. These risks include long-observed phenomena like ionizing radiation, weightlessness, with its attendant loss of bone mineral density, noise and toxic exposures, and as well as more recently detected issues like microgravity ocular syndrome. Just as systematic assessment of the mechanical hazards to spacecraft during launch, landing and on orbit is an indispensable tool in the management of technical risk, a thorough grasp of the short- and long-term human physiological response to spaceflight is imperative to inform future policies and procedures for managing health risk. Unfortunately, no comprehensive occupational medical surveillance program for NASA astronauts exists today. In the absence of methodical medical surveillance and care for those exposed to these health risks, we are irretrievably losing an invaluable source of data, and are severely hampering our plans to extend human presence beyond low Earth orbit. The former and current astronaut cadre is the only study population that can facilitate our understanding of past and future space-related health risks; it is unforgivable to not monitor their health, and collect and analyze the relevant associated data.

PROPOSED SOLUTION

The nation needs a dedicated astronaut occupational medical program, oriented toward surveillance for effects of the health risks associated with spaceflight and the diagnosis and treatment of resulting health consequences. Such programs exist for the nuclear workers of the Department of Energy, the Department of Defense, and the civil nuclear power industry. The DOE's Former Worker Medical Screening Program provides ongoing medical screening examinations, at no cost, to all former DOE federal, contractor, and subcontractor workers who may be at risk for occupational diseases (National Defense Authorization Act 1993; FWP Office of health, Safety, and Security). Workers are monitored carefully for radiation doses acquired during their work careers, and undergo medical surveillance following retirement for health effects that may be causally related to their occupational radiation exposures. Similarly, workers exposed to industrial dusts, such as miners and foundry workers, are monitored for known diseases whose incidences increase due to these exposures. Both the operation of target organ systems – lung function in this case – and resulting illnesses, including asbestosis, mesothelioma, and silicosis, are followed. It is important to monitor both for function of target organs at risk as well as the known specific illness tied to these risks. In these industries, there is a recognized obligation to provide both comprehensive monitoring and health care for risks attributable to the workplace. Similarly, NASA has a moral and ethical obligation to provide appropriate long-term surveillance, diagnostic and therapeutic support to current and former astronauts for health conditions related to their work environment, as well as to facilitate the expansion of human exploration beyond low Earth orbit.

HUMAN HEALTH HAZARDS IN SPACEFLIGHT

Radiation

Ionizing radiation is a fundamental aspect of the space environment, with exposure levels much higher than those encountered in any natural terrestrial setting. Astronauts are exposed to a complex milieu of radiation that differs qualitatively and quantitatively from terrestrial radiation sources. Space sources include Earth's geomagnetic fields, solar particles, and galactic cosmic rays (GCR), as well as secondary particles produced when high energy ions impact spacecraft and habitat structures (Operational Radiation Safety Program NCRP Report 142). With the energies and spectra encountered in spaceflight, radiation is and most likely will continue to be the major limitation to human space exploration for the foreseeable future.

Ionizing radiation is known to have many deleterious effects on human health. The combination of the wide spectrum of radiation types and energies inherent in spaceflight together with the negative effect on human health make this an especially complex hazard. It is important to emphasize that the radiation health hazard impacts nearly all aspects of human spaceflight, including vehicle and habitat design, mission duration, exploration mission architecture, crew selection, and monitoring. Although human spaceflight currently operates in a radiation risk zone that has not demonstrated immediate negative health impacts from these radiation exposures, adverse effects may take many years to emerge. These risks require long term statistical analysis of flight crew populations to identify and document medical risks from space radiation.

The main medical risks associated with the spaceflight radiation exposure include increased cancer risk, degenerative tissue disease, and possible central nervous system effects. In particular, increased incidence of cancer is a well-known consequence of radiation exposures. Currently, U.S. astronauts work under a career exposure limit that corresponds to a 3% predicted increase in cancer death, tracked as a Risk of Exposure Induced Death (REID). The radiation dose corresponding with the 3% risk is individualized, and is gender and age weighted based on extrapolated data from ground populations. Models used to determine risk levels are still very developmental, and there is considerable uncertainty in predicting consequences of a specific space radiation exposure. Uncertainty is reduced by applying conservative scaling factors. However, the uncertainties of models, combined with conservative scaling factors and limits as applied to actual radiation doses encountered, profoundly affect both individual flight careers and future exploration scenarios.

Astronauts are meticulously monitored for acquired radiation dose during their active flight careers, similar to terrestrial radiation workers. However, the U.S. Government does not provide long term screening to astronauts or treatment for illness which may be space radiation related. This lack of monitoring negatively affects our understanding of the epidemiology of spaceflight, since some of these cancers may not be captured without long term surveillance following active flight careers. Most importantly, survival from most types of cancers is highly dependent on the stage of disease at diagnosis. If a long term screening program similar to what has been implemented in other sectors of government is not in place, astronauts risk later detection and thus worse outcomes of any radiation related cancers. Additionally, there is evidence that radiation induced cancers may be more aggressive than their non-radiation associated counterparts. Clearly, a comprehensive and aggressive lifetime screening program for radiation induced or enhanced cancers is obligatory to find, treat and understand cancers caused by space radiation. Such a program will identify likely cancer types and screening schedules to optimize long term health outcomes. This knowledge base will be systematically built, and will be applied to REID endpoints to determine if radiation limits can be safely increased.

Other radiation health effects are known; however, their relationship to spaceflight radiation exposure is even less quantifiable than cancer. Degenerative tissue diseases associated with ionizing radiation include cataracts, cardiovascular disease, and gastrointestinal disease (Little et al. 2012). Although these issues and diseases have been identified in ground populations exposed to radiation, space flight limits cannot yet be defined due to multiple confounding factors. Likewise, animal studies suggest that long term central nervous system effects, including dementia, Alzheimer's disease, and premature aging, may be associated with large doses of ionizing radiation (Cucinotta, 2012). Much more research is needed to determine actual relationships and mechanistic contributions. However, it is prudent to perform long-term health screening of astronauts for degenerative tissue diseases and central nervous system effects.

Microgravity Ocular Syndrome (Visual Impairment and Intracranial Pressure - VIIP)

In the past few years, a constellation of findings associated with weightlessness involving eye structures and the central nervous system has been identified. The overall syndrome involves swelling of the optic nerve head (optic disc) of the retina, swelling and distension of the optic nerve sheath behind the eye, flattening of the globe of the eye causing a hyperopic vision shift, and small but significant increases in intracranial pressure (ICP). Subjectively, crewmembers note only degradation of visual acuity, with near vision worsening over time on orbit and requiring stronger corrective lenses (Mader et al., 2011). Prevalence of this syndrome is high, exceeding 50% in long duration flyers, with a strong male predominance. Subtle changes have been seen even in astronauts after short duration Space Shuttle missions (Kramer et al., 2012). Determination of ICP involves performing a spinal tap, and this has been done in only a small number of crewmembers postflight. In spite of the anatomical findings seen, crewmembers are not functionally impaired with adequate vision correction; as such, routine performance of spinal taps is not clinically justified. However, indirect findings based on imagery do suggest a small to moderate increase in ICP in the majority of individuals. Currently, there is no direct knowledge about ICP inflight. These vision and anatomical changes may persist in some astronauts postflight, suggesting permanent tissue remodeling.

Microgravity ocular syndrome likely involves adaptive responses to weightlessness that have not yet been recognized, and is one of the most significant physiologic discoveries in human spaceflight. Although only recently recognized, this syndrome is almost certainly not new. Anecdotal reports of vision shifts have been noted for decades among U.S. and other crewmembers. Russian medical specialists noted optic disc swelling in postflight examinations of long duration crewmembers following Mir missions. However, modern diagnostic tools have helped to bring the magnitude of this issue to light. These tools include 3-Tesla magnetic resonance imaging, optical coherence tomography, high definition retinal imagery, and optical ultrasound, the latter two of which may now be performed inflight. The cause and mechanism of microgravity ocular syndrome remain unclear, and are the focus of intensive investigation. A driving factor is most likely the headward fluid shift that occurs in weightlessness, along with other changes in vascular and fluid regulation. Additional factors being studied include high carbon dioxide levels found on spacecraft, heavy resistive exercise, and possible individual metabolic characteristics (Bowman et al., 2013).

Musculoskeletal Injury

Musculoskeletal injuries are occupational risks astronauts face throughout their careers. These injuries often result from daily cardiovascular and weight training, both on the ground and on-orbit. Prior to flight and typically over a period of several years, extensive training is required for astronauts to effectively perform the required tasks needed for space walks, or EVA (extravehicular activity) in a pressurized space suit. In space, daily two-hour exercise sessions are required to counter bone and muscle losses caused by microgravity.

Musculoskeletal injuries are also directly related to the EVA training, which is performed in the spacesuit in the Neutral Buoyancy Lab (NBL). This underwater simulation permits crew members to practice the actual hands-on maneuvers, but requires use of heavy tools, performance of overhead tasks, and working in inverted positions in a 300 pound spacesuit. The suit design results in impingement on the shoulder, specifically limiting scapulothoracic motion. Numerous 6-hour training sessions in a pressurized suit have resulted in a variety of musculoskeletal injuries. Rotator cuff tears, tendonitis, bursitis, and labral tears of the shoulder are common (Viegas et al., 2004). Elbow injuries are also common and include medial and lateral epicondylitis. Since 2002, there have been over 100 cases of shoulder injury, more than a dozen of which required surgical repair, along with several elbow injuries which have required surgery (Scheuring et al., 2009). This training is an occupational hazard with complications that may persist long after employment.

Postflight, astronauts are also at risk of spinal herniated nucleus pulposus (HNP), commonly known as herniated disc. In the immediate 12-month postflight time period, the incidence of both cervical and lumbar HNP is 4.3 times higher in the astronaut population than in controls (Johnston et al., 2010). This is believed to be related to expansion of intervertebral discs during axial unloading in weightlessness. Approximately one quarter of the astronauts with a diagnosis of HNP in the study ultimately required cervical or lumbar surgery.

The extensive history of musculoskeletal injury requiring surgical repair indicates that long term follow up is required to fully understand the impacts of training and spaceflight on crew members. This follow up will also provide valuable information about spacesuit design and countermeasures to prevent injury.

Changes in Bone

Loss of bone mineral density caused by spaceflight is well documented. Detailed studies have determined that microgravity enhances the bone resorption (breakdown) process, particularly in weight-bearing bone structure. Unfortunately, in microgravity, this process is uncoupled from bone formation (Sibonga et al., 2008). The spaceflight average loss for crew members is 1-1.5% bone mineral density per month. This is significantly more than post-menopausal females, who lose 0.5-1% bone mineral density per month. The mechanism of imbalance between bone resorption and formation during spaceflight is now understood based on measurement of various biochemical bone markers of bone formation and resorption. In addition to bone mineral density loss, there are also changes in subcompartment bone as shown by quantitative computed tomography (Carpenter et al., 2010). Mechanical analysis of the bone data suggests that hip strength is reduced after 6-month spaceflight missions (Seemen et al., 2001; Sibonga et al., 2008). These bone changes are significant. To date, two crew members have suffered hip fractures 15-18 months after returning from long duration spaceflight.

Countermeasures to minimize these bone mineral density losses during spaceflight include heavy resistive exercise, bisphosphonate drugs, and nutritional supplementation. Improved exercise hardware (Advanced Resistive Exercise Device (ARED) and advanced treadmill) together with bisphosphonates and better nutritional management have demonstrated improvement in astronaut bone density over previous countermeasures. However, ongoing detailed studies are necessary to understand the complexities of bone quality and the ability to recover bone strength after spaceflight. In addition, there is the added risk of providing bisphosphonates to a population that is younger than the age group these drugs were designed to help, which may cause unanticipated long term health impacts to the astronaut population.

Occupational Exposure to Substances

Historically, astronauts have been exposed to a variety of toxic materials, including formaldehyde (Shuttle, MIR, ISS), urine pre-treat solution containing sulfuric acid and hexavalent chromium (ISS), cadmium (ISS water supply), combustion event contaminants (MIR), ethylene glycol (MIR), methanol (ISS), iodine (STS-1 through 85), nitrogen tetroxide (Apollo Soyuz Test Project), mold (MIR, ISS), Freons and other halocarbons, CO2 and CO. In some cases, degradation of life support equipment over time has resulted in crew exposure to significantly higher levels of trace impurities, for example total organic carbon in the water (ISS). Obviously, these exposures occur in a closed environmental system that the crew cannot leave and must remain in until mission conclusion, despite residual levels of toxic components. Typically, the levels of the contaminants are managed based on toxicity or criticality, likelihood of occurrence, and ability to “scrub” the environment after a toxic event.

While some occupational exposures to this list of chemicals may result in short-term effects, such as chemical burns from urine pre-treat solution or airway irritation from exposure to ethylene glycol, chronic effects require an occupational surveillance program specifically targeting suspected potential outcomes from specific exposures. For instance, formaldehyde exposure has been associated with a greater risk for nasopharyngeal and lung cancer; elevated cadmium levels are associated with chronic kidney disease.

Since these exposures occur in concert with decreased immune function and exposure to ionizing radiation, it is challenging to isolate the impact of specific toxic events. Other government agencies (DOE) provide congressionally-mandated programs to screen for potential adverse health effects for some of these sorts of substances.

Immune System Effects

The immune system is adversely affected by spaceflight (Gueguinou et al., 2009). Recent studies have identified quantifiable changes in immune function, including T cell, natural killer cell, monocyte and neutrophil function, cytokine production patterns, and latent viral reactivation. Factors which may contribute to altered immune response during spaceflight include radiation, physical and psychological stress, persistent circadian misalignment, nutritional deficiencies including antioxidants and vitamin D, and air quality and particulate levels. Microgravity may also directly suppress immune function. Additionally, some microbes may become more virulent in microgravity. Here on Earth, immune system problems can contribute to increased incidence of infection, allergies, hypersensitivities, autoimmunity and increased risk of tumor formation.

Crewmembers have experienced allergic symptoms and rashes during spaceflight which may be related to altered immune responses. Crewmembers who have no allergies on Earth have suffered sneezing and itchy eyes that required daily allergy medication for their entire long-duration mission. The incidence of rashes during spaceflight is 75 times greater than on Earth (Ilcus et al., 2009). These rashes can persist for months, and resist effective treatment. In addition, delayed healing from cuts and scrapes has also been reported.

These observations are consistent with scientific data that demonstrate alterations in immune function during spaceflight. However, consequences to long term crew health are not known. While further research is necessary to determine the actual risk levels for astronauts during spaceflight, these potential clinical outcomes could have either acute or chronic impacts on long duration missions (Crucian et al., 2009), along with long-term effects on occupational health.

SUMMARY

There is a moral and ethical obligation on the part of any employer to exercise due diligence to study all occupational hazards that its employees may encounter in the workplace, to understand the short- and long-term health effects of those dangers, to use all reasonable methods to prevent these risks from negatively impacting the wellbeing of its current and future workers, and to provide care for former employees who suffer health issues as a result of their service. There are a number of significant human health risks associated with flying in space, in addition to the considerable physical hazards of dynamic flight phases. Many of these perils are unique to the spaceflight environment and most evade our full understanding. It is clear that we must do our utmost to mitigate these risks for the cadre of current and future American astronauts by assiduously monitoring the health and, where applicable, treatment of their predecessors. This information is absolutely imperative for the design of missions, vehicles and countermeasures for exploration of space beyond low Earth orbit. Finally, there is a public right to understand the comprehensive effects of spaceflight on human health as the democratization of access to space becomes a reality with the successes of commercial human spaceflight.

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