# The Risks To Human Health In Extended Space Exploration

## Abstract

Health risks associated with long term space flight are generally categorised into two main causes: reduced gravity and space radiation. The current numbers of astronauts, either retired or current, is often not sufficient to form conclusive suggestions. Overall, there is very detailed analysis of the functional risks to the body outside of low Earth orbit and for long term loss of normal gravitational forces. However, there is a disparity in countermeasures to protect astronauts embarking on long term missions, especially to Mars.

## Introduction

Current ambitions by various space organisations of long term space exploration outside of low Earth orbit (LEO) and the protection the magnetosphere and atmosphere provide, with known and unknown risks, especially in terms of the effects of space radiation and long term exposure to low gravity. The currently known risks are mostly in relation to long term effects of microgravity. With plans of manned missions to Mars, the effects of low gravity, that are currently studied in approximate six month intervals, may be insufficient given the anticipated six month journey to the planet each way, along with a proposed 18 months on the surface of a planet with only 38% of the gravity experienced on Earth (Weber et al. 2019). With such a small population of astronauts who have experienced low gravity, let alone ventured outside of LEO, many studies have difficulty drawing accurate and long term conclusions. This review of literature explores the effects spaceflight has on the body and current proposed countermeasures to aid long term space exploration.



## What influences the body during space flight?

### Microgravity

Microgravity experienced during space flight is well documented by astronauts onboard the ISS, with severe results to the bodily function experienced after long term exposure without countermeasures. Bone and muscle atrophy is most commonly observed, with active countermeasures in place currently to reduce the impact when astronauts return to the regular gravity of Earth. Other concerns include strain on organs such as those part of the cardiovascular and digestive systems, along with risk to health of brain structural integrity and stem cell health. Of highest concern is areal bone mineral density (aBMD) decay, especially in loading sites of the body, such as the lumbar spine, hips, knees and heels (Orwoll et al. 2013). The use of resistance exercise in conjunction with aerobic exercise is employed on the International Space Station, with a resulting decrease in aBMD lost. A study conducted with seven astronauts performing missions of four months of longer added supplementation of bisphosphonates, in the form of medication commonly used to treat osteoporosis, showed a significant reduction in the aBMD lost, with an increase observed in the density of the lumbar spine (LeBlanc et al. 2013).

## Bone Density Loss

The potential adverse effects of prolonged weightlessness, as reported from the results of the NASA Bone Summit (Orwoll et al. 2013), include concern for risk of fracture after returning to normal gravitational forces, and a potential risk of developing premature osteoporosis. Generally, a 10-15% decline of bone mass density can still allow astronauts to meet the NASA standards. The risk of damage to key loading sites of the body, such as the hips and lumbar spine, along with the knees and ankles, are closely studied to determine risk of premature decay to the areas. Concern for swelling of intervertebral disks of the lumbar spine has been raised in conjunction with observations following bed rest studies, with the implication of long term or chronic lower back pain. Bailey et al. (2018) determined that while bone mass deteriorated, the main risk to lumbar spine stability after long term missions in microgravity was atrophy of the multifudus muscles that surround the lumbar spine. Pre-existing vertebral plate insufficiency, however does increase risk of chronic lumbar spine pain in astronauts who experience microgravity. The hips support a large proportion of the body’s mass, and the loss of skeletal integrity experienced after return from microgravity presents and increased risk of fracture that would not normally be expected. With the current technology used to analyse the aBMD of astronauts is not able to fully detect skeletal changes, thus potentially being unable to assess the risk of fracture adequately (Michalski et al. 2019). There is limited connection between sex and decay of bone density (Ploutz-Snyder et al. 2011). Recommendations from the NASA Bone Summit (Orwoll et al. 2013) include more thorough scanning tools be used, rather than the current dual-energy X-ray absorptiometry (DXA) used. Recommendations to use a quantitative computed tomography (QCT) are widespread (Michalski et al. 2019, Orwoll et al. 2013, Sibonga, 2013) as it provides a three dimensional image which will provide a more detailed analysis. With more in depth scanning of loading sites, analysis of results, alongside supplementation and more intensive loading exercises can aid in prevention or reduction of aBMD loss during space flight.

## Muscular Atrophy

Loss of mechanical loading to the body results in deterioration of muscle tissue, hence the need for resistance exercise and aerobic exercise to reduce muscular atrophy. However, despite astronauts partaking in exercise, muscle mass reduction is often observed due to the lack of gravitational forces that the body generally uses a combination of muscle and bone density to resist. Issues in relation to long term space flight include the transport of bulky and potentially fragile equipment. Transport of such equipment may not be practical to the surfaces of the moon and Mars, thus alternative methods of simulating similar levels of loading on joints must be developed (Weber et al. 2019).

## Structural Plasticity of the Brain

Koppelmans et al. (2016) explored the effects microgravity have on the structural plasticity of the brain, mainly volumetric changes in grey matter after Low Earth Orbits ranging from two week space shuttle missions to approximately six month long missions on the International Space Station. Existing evidence of inflight spatial disorientation, reduced mass discrimination and increased manual tracking errors under cognitive load have been observed in astronauts, although gradual adjustment of sensorimotor processing occurs alongside body unloading. Evaluation of retrospective magnetic resonance imaging scans were compared to preflight imaging from 27 astronauts with missions angling from two weeks to approximately six months.

Widespread volumetric decreases of grey matter were observed, with some localised increases. The structural brain changes that occur during space flight are possibly related to fluids in the brain shifting or general neuroplasticity (Koppelmans et al. 2016).

**Stem Cells**

Contact forces provided by the Earth are required for many physiological functions to perform as designed. The mechanical unloading experienced in tissues due to microgravity poses higher risk in long term flights, particularly in terms of stem cells. Low gravity has been observed to partially inhibit the ability of progenitor cells, which are slightly specialised stem cells, to transition to terminally differentiated adult cells by Blaber et al. (2014). The results of the study performed on stem cells on the ISS also showed an impairment of embryonic stem cells to express any differentiation, rather they maintained the stem ability. The inhibition of stem cell based tissue regeneration can lead to detrimental health effects in long term spaceflight.

## Radiation

The three main sources of radiation are from solar particle events (SPEs), galactic cosmic rays (GCRs) and geomagnetically trapped particles within the Van Allen belts that exist within LEO (Bahadori et al. 2019). The known effects of ionising radiation include: carcinogenesis, degenerative tissue effects such as cardiovascular diseases, cataracts, premature ageing and immunological changes, damage to the central nervous system, DNA lesions and acute radiation sickness (Chancellor et al. 2014).



**Cataracts**

Indications that astronauts that have been exposed to space radiation are susceptible to the long term effect of radiation causing cataracts, which has a high risk of expression in personnel who will take place in long term missions to the moon or Mars, along with risk for current International Space Station astronauts. The protection of the magnetosphere has the potential to increase the safe amount of time one can exist outside of the atmosphere, although lower energy particles are trapped at the same level above the earth as where the ISS sits. The first report of the NASA Study of Cataract in Astronauts (NASCA) (Chylack Jr et al. 2009) began the long term study of the severity and progression of lens clouding comparatively between astronauts exposed to any level of radiation, and subjects of similar peer groups. The initial findings showed that the largest opacities in the lenses were seen in astronauts who were exposed to the highest levels of radiation, namely Apollos astronauts and long term LEO astronauts who work on the ISS.

**Cardiovascular Disease**

The risk of cardiovascular disease (CVD) has been linked to a higher relative mortality rate in astronauts from the Apollo missions (Delp et al. 2016). A higher incidence of cardiovascular disease has been linked to career astronauts, despite statistical evidence that astronauts are generally at a lower risk, disregarding familial history (Ade et al. 2017). Currently accepted understanding is that exposure to ionising radiation, such as SPEs and GCRs, increases the risk of cardiovascular diseases, as seen when comparing the CVD related mortality rate of astronauts who did not leave low Earth orbit those that did. Although sample sizes of the comparison groups are small, the trend seen is that LEO astronauts, such as the Gemini and Mercury astronauts, have a lower incidence of CVD than the Apollo astronauts (Delp et al. 2016).

**Immune System**

As reported by Kennedy (2014), immune system changes have been observed in animal studies when exposed to simulated space radiation, especially in conjunction with simulated microgravity. Changes in immune cell protein secretion (cytokine) production, leukocyte subset production and antibody production have been demonstrated to have a detrimental effect on survival rates. These alterations to immune function are similar to those experienced when exposed to pathogen associated molecular patterns (PAMPs), and extended exposure to these patterns can lead to long term immune system dysfunction. Other long term immune system responses to exposure to high dosages of radiation include a higher mortality rate in animal test subjects, a higher risk of malignancy in lymphoma and rare tumours.

## Countermeasures to allow long term space exploration

### Nutrition

Improvements in nutrition for astronauts will help to maintain physiological health, such as immune health and bodily ability to maintain bone and muscle density. The vitamins necessary have a tendency to deteriorate at high temperatures. Low water formulations in the form of compressed granola bars and drink powder have been tested to yield retention levels above the space flight requirement over three years when stored at or below room temperature (Barrett et al. 2018) Elevated levels of calcium excretion after exposure to low gravity have been observed since the Gemini and Apollo astronauts in the 1960s to early 1970s. A general incidence of 1.0-1.5% loss of bone mass density per month of spaceflight is witnessed in current ISS astronauts (Smith et al. 2012). Recommended countermeasures include the supplementation of diet and exercise with bisphosphonates, which help inhibit resorption. LeBlanc et al. (2013) demonstrated a significant reduction in aBMD loss in a sample group of seven astronauts when supplementing their exercise routine with bisphsophonates.

### Exercise

Exercise to is used to counteract muscle and bone atrophy. Astronauts on the ISS are currently using a combination of aerobic and resistance exercises, with simulated gravity of 70% of that experienced on Earth. With space organisations having plans of long term exploration of the moon and Mars, the machinery used on the ISS may not be practical to transport to the surfaces. Weber et al. (2019) have proposed the use of plyometric exercises such as hopping can generate enough mechanical loading to reduce deconditioning.

## Protective Measures

Protective measures against radiation include the use of antioxidants to counteract the oxidising effects ionising radiation can have on cells (Kennedy, 2014) and shielding materials. Current materials and techniques are only effective against solar particle events, but not against highly charged galactic cosmic rays (Townsend et al. 2018).

## Conclusions

Overall, there are large quantities of studies concerning the effects of microgravity on bodily function and the beginnings of studies on the effects of ionising radiation on the body. Further exploration of protective measures should be undertaken to be able to adequately protect astronauts as best as possible.