A journey to Mars: The medical challenges associated with deep space travel and possible solutions

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In the summer of 2016, the Canadian Space Agency began accepting applications for the next generation of Canadian astronauts.[1] To date, only twelve Canadians have ventured beyond the limits of our atmosphere, five of whom were medical doctors.[2] A physician's mindset is calibrated for high–stakes decision–making and is useful for making health decisions in a hazardous extraterrestrial environment. To some degree, the knowledge base that physicians bring to healthcare on Earth can be translated to providing healthcare in space. However, the environment in space poses complex health challenges that are difficult to overcome even with continuous advancements in technologies.[3-5] Space agencies rely on technology for providing out–of–this–world healthcare to maintain the health status of their astronauts during space missions.[3,6]

While astronauts are in space, their bodies adapt to the new environment in ways that are often pathologic. Bone demineralization, cardiovascular dysfunction, and muscular atrophy are a few of the many physiologic responses to the pathologic microgravity environment.[3,5,7-8] Radiation exposure is another major hazard for astronauts. All of the above issues are exaggerated when considering a mission such as travelling to Mars.[6,9-10] While a great number of health challenges have been identified in space travel, constant technological advances are bringing humanity closer to its first interplanetary journey.[3,9,11]

The next major step for humans in space exploration will be to put an astronaut on Mars and bring them home safely. Fortunately, after landing multiple unmanned space craft on the planet's surface, many of the logistics of travelling to Mars are well–understood.[12] With NASA hoping to take astronauts to Mars in the 2030s, the largest barrier is in developing technology that will keep astronauts safe for an unprecedented amount of time in space.[13] The current record holder for longest duration of space flight is Valery Polyakov, who was in a near–Earth orbit for 14.9 months, and experienced great difficulty with walking upon his return to Earth.[14] Located approximately 50 million kilometers from Earth, it is estimated that a return mission to Mars would take approximately 30 months.[13,15] The amount of effort required to advance medical technology in order to facilitate such a journey is likely to necessitate terrestrial efforts. In the past, work by NASA has contributed to the development of many medical technologies such as MRI, CT imaging, and left ventricular assist devices.[16-17] Consequently, this commitment to advancing the physical reach of humans in space may have unforeseen benefits for physicians back on Earth.

The first step in ensuring astronaut safety is in the rigorous screening process prior to boarding any space craft. Astronauts undergo exercise, endurance, and strength testing, as well as preflight nutritional assessment and psychological interviews.[3] Astronauts must have healthy kidney function, and carry low risks of coronary artery disease.[3] Astronaut DNA is assessed preflight for any previous damage or signs of marked susceptibility.[6] To reduce astronauts' risk of radiation–induced cancer, NASA excludes smokers because of their underlying cancer risk.[6] Female and young astronauts are at a higher risk for radiation–induced cancer because of differences in body composition and expected longevity following exposure to space, respectively.[6]

In addition to the preflight testing, inflight testing will be an essential component for ensuring astronaut safety on a mission to Mars. A space craft can carry a limited supply of medical equipment for emergency situations and regular monitoring. In the past, this has included ultrasound machines, serum analysis technology, ECG, defibrillators, restraints, and over 190 medications.[3,18] During space flight, astronauts have regular meetings with psychologists, as well as checkups that include exercise tolerance tests, radiation monitoring, and blood chemistry assessments.[3] Despite the pre– and inflight health assessments, fully understanding the human body's complex adaptations to long term microgravity is an ongoing challenge for space agencies.

One of the better known health complications for astronauts is the risk of bone loss and muscle atrophy in microgravity. In accordance with Wolff's law, bone will remodel according to the stress, or lack thereof, placed on it.[4] In space, ten percent of proximal femur bone mass can be lost in six months, representing a rate of bone loss that is ten times greater than that seen in osteoporosis.[5] In addition, rapid bone resorption in space can cause an increase in serum calcium to levels that may predispose astronauts to kidney stones; however, as with other medical research conducted on space travelers, studies demonstrating this effect struggle with small sample sizes and have low power.[5] Despite such limitations, the trends toward musculoskeletal depletion noted in astronauts during and following space travel prompted space agencies to recognize that for longer duration missions, bone loss must be combated. This began with the use of aerobic exercise machines with relatively high intensity exercise regimens.[5] Despite these efforts, total bone loss was still reported at 0.35% per month, leaving astronauts struggling to adapt to life back on Earth with the full force of gravity on their skeleton.[19] With this knowledge, more studies have been conducted to determine ideal diets and exercise regimens for astronauts.[11] A recent study that prescribed resistance exercise via an Advanced Restrictive Exercise Device found that astronauts undergoing this regimen did not experience significant bone loss.[5] In order to achieve these results, astronauts performed 2.5 hours of physical exercise six days per week while in flight.[20] Additionally, the use of bisphosphonates has recently been suggested for astronauts because of their effects in slowing bone loss in bedridden patients.[11] Through the combined effects of these innovations, astronauts are able to significantly reduce their risk of bone loss, which is a key factor in long–duration space travel.

Despite the progress in methods to prevent bone loss, there are many more health–related challenges to overcome before safely sending humans to Mars. One such challenge is the risk of radiation

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exposure in space. To date, no astronauts have endured long–term missions outside of Earth's geomagnetic field, which protects us from high–energy protons called Galactic Cosmic Rays (GCR).[6,9] In years past, many biological specimens have been sent into space to test the impact of radiation.[21] In these studies, significant rates of anomalies and changes in reproduction have occurred, with more extensive damage affecting specimens provided with Earthlike pressurization and oxygen content, allowing normal metabolic activity to take place.[21] Consequently, this risk is well–known to space agencies, and steps are currently being taken to minimize risk for future astronauts. The first level of protection is in screening astronauts for pre–existing DNA damage or susceptibility.[3,6] The second level of protection is related to a moral decision to be made by space agencies regarding how much radiation is an acceptable risk.[6] Thus far, NASA has adopted the Occupational Safety and Health Act (OSHA) of American workers which limits astronauts to a maximum of a 3% lifetime risk of exposure–induced fatal cancer.[6,10] While the annual dose limit in the United States is 50 millisieverts (mSv), most workers, such as radiotechnicians, reactor workers, or pilots, only receive between 1 and 5 mSv per annum. Meanwhile, a six–month stay on the International Space Station can expose an astronaut to 80 mSv.[10] With current technology, NASA estimates that a 30–month mission to Mars within a 5g/cm2 aluminum structure would expose astronauts to over 900 mSv, far beyond safe or acceptable OSHA limits.[6,10,22] NASA is currently working toward technologies that can protect astronauts from GCRs for long–duration missions. A hydrogen–rich barrier is best suited to prevent damage from GCRs, and items such as water or household plastics have been shown to be effective in this regard.[9] However, using either of these for a layer of protection may be difficult given the other requirements of a space craft. Recently, NASA has created hydrogenated boron nitride nanotubes that are heat–resistant and hydrogen–abundant, meaning that they confer significant protection from GCRs.[9] NASA has also proposed that a type of radiation bunker be used in case of any solar flares that may arise during a mission.[9] This technology will be essential for future travel to Mars, as the atmosphere of this planet provides very little protection from radiative forces.[9]

Radiation and bone loss risks aside, there are many more impacts of microgravity on the human body that remain understudied. Changes in cardiovascular function are significant in astronauts, as their hearts adapt to pumping against less resistance in space.[7] Among returning astronauts, 85% failed a tilt table test due to cardiovascular deconditioning incurred in space.[3,7] Astronauts have also reported visual anomalies that may be a consequence of radiation exposure.[23] Additionally, approximately 52% of astronauts have reported back pain in space, and many can also experience fatigue.[3,8] Evidently, there is much to be learned in this field regarding the pathophysiology of these health problems, as well as possible solutions. However, with the advances made in the fields of bone density retention and radiation exposure prevention, it is feasible that technology will be developed to combat these other medical complications.

Space travel has always been a unique exercise of combining the best of human potential to conquer incredibly complex challenges. The collective action of humans in achieving travel between Earth and space has taught scientists and physicians about the impact of microgravity on human health. Very quickly bone loss, muscle atrophy, and radiation exposure were recognized as significant risks in space flight, and many steps have been taken to counteract these effects. More recently, far more complications have been discovered, including visual, psychological, and cardiovascular pathologies. The plans of major international space agencies to travel to Mars through unprecendented levels of radiation or durations of space flight intensifies the associated risk of all of these health complications. However, space agencies remain dedicated to finding solutions to these problems through development of radiation barriers, machines for preventing bone loss, specialized nutritional supplements, and more. Space medicine is an incredibly unique field of medicine necessary for enabling humans to discover our ever-growing collective potential. In space, just like on Earth, medicine is of ultimate importance, and health professionals play a key role in enabling humanity to put its first footstep on the red planet.

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