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How Does Spaceflight Affect the Human Body?

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Abstract

Spaceflight can impact just about every organ of the human body. The launch into space increases gravitational forces, which may decrease consciousness. Once subjected to the microgravity of outer space, the constant mechanical stress exerted on the body from Earth's gravity decreases enormously, causing bone degeneration to occur. Calcium, a major component of bone is excreted in very high amounts, often leading to the formation of calcium kidney stones. Astronauts perform weight bearing exercise, take osteoporosis drugs and calcium and vitamin D supplements in order to combat bone loss. The vertebrae of the spine are also impacted by the lack of gravity. The spine actually expands up to two inches. On Earth, gravity pulls all the liquid of the body to the lower extremities. Without gravity, the liquids are equally dispersed throughout the body causing faces to appear puffy and increasing pressure on the brain due to excessive cerebrospinal fluid. The body responds to this liquid buildup by eliminating plasma and red blood cells, causing anemia. The increased fluids flatten astronaut's eyeballs, and they often experience farsightedness. The immune system is also impacted during spaceflight as T-cells are not activated properly. Astronauts are also impacted by an excess radiation, which can increase the chances of future occurrences of cancer or cataracts. Muscle atrophy takes place as a result of microgravity as well as other factors. Exercise along with growth hormone, are recommended in order to combat the muscle degeneration. In space, the vestibular system of the ear does not function properly and impairs proper balance which can result in space motion sickness. Although many may not be aware, the benefits of the space program have impacted most everyone on Earth; as there have been dozens, if not hundreds of inventions and discoveries which were only developed because of the space program. Although the space program has benefitted humankind, the risks to the fragile human body are gargantuan. It would be preferable to continue the space exploration program remotely via robotics.

Introduction

Since the middle of the nineteenth century, and perhaps even much earlier, mankind has been enthralled by the idea of space exploration. Back in 1865, Jules Verne envisioned space travel via a projectile shot at high speed out of a gigantic cannon in "From Earth to the Moon." In 1901, H.G. Wells envisioned space travel in a space "sphere" in "The First Men on the Moon." This was closely followed by the very first science fiction movie: Mieles' "A Trip to the Moon", a silent movie based on Jules Verne's earlier tale.

Our unquenchable fascination with space travel continues until this very day. In fact, science fiction movies have been among the top grossing movies of all time. One only has to think of the six Star Wars movies (with more episodes coming), E.T., the numerous Star Trek series and spinoffs and countless other hugely popular fictional productions.

It is even possible that these many popular works of fiction depicting the ease of future space travel may have enabled the reality of Nasa's Project Mercury (1958 – 1963) and the subsequent Apollo space program (1961 - 1975). The dream of space exploration was further attained in the Skylab project (1973 - 1979), the Mir Space Station (1986 – 2001), in the International Space Station (assembled starting from 1998; manned since 2000 - present) and the Space Shuttle Program (1981 - 2011). Our expectation of human space travel to alien worlds continues to this day, as scientists envision establishing a colony on Planet Mars. And Richard Branson of Virgin Atlantic has created Virgin "Galactic", with plans to allow any person who has $250,000 to burn to experience space travel in the private sector.

One thing in common in most of the previously mentioned works of fiction is that they all seem to imply that it will be pretty easy to get anywhere we want to go in the galaxy and even beyond. What the general public fails to understand, however, is the grim danger one faces every moment spent in space. Our bodies are just not created to exist in space. This paper reviews the research conducted regarding the many things that can injure, maim or even kill those who dare to travel into space and recommends a safer alternative via robotics.

Discussion

From the very first moment, travel to space is fraught with acute danger to the human body. The launch of a rocket ship places unique strains on the body. On Earth, normal gravity conditions are termed "1-G". As the rocket accelerates toward outer-space, however, the G-forces increase to 3-G or more. An excessive G-force can have many deleterious effects on the body: The heart loses its ability to pump blood efficiently; circulation of the blood is impaired and oxygen is prevented from reaching the brain or other organs sufficiently. Consequently, a decrease in consciousness may occur: Colors may begin to fade; vision may be limited to tunnel vision; and a total blackout may even occur. While the G-forces usually do not have such serious side-effects at takeoff, the effects can be much more severe upon reentry into the Earth's atmosphere since the astronaut's body is in a much more weakened state after a stay in space. (Harrison, 2001)

On Earth, the average human head weighs approximately ten pounds. However, if one experiences 3-G's, the weight is tripled, placing enormous strain on the neck muscles which can result in severe neck pain. Therefore, astronauts are strapped into specially made seats which provide extra support to sensitive areas, such as the cervical and lumbar regions. Astronauts also sit facing the direction of acceleration, in order to spread out the forces evenly over the body. (Harrison, 2001)

Upon reaching outer space, the hazards continue to multiply, but for the opposite reason. During takeoff, an astronaut is subject to the force of 3-Gs or more. On the other hand, in outer space there is minimal gravity which can also adversely affect many organs of the body.

A major organ which degenerates during space travel is bone. Although bone may seem static, it is actually a dynamic, living tissue. There are three types of cells found in bone dynamics: osteoblasts, osteoclasts and osteocytes. Osteoblasts are responsible for the formation of osteocytes; which are responsible for the deposition of bone. Simultaneously, osteoclasts resorb bone. This coordinated process of bone degeneration and the formation of new bone is intensified by mechanical stress. (Caetano-Lopes et al, 2007) Therefore, perhaps the most serious hazard faced by astronauts is the effect of microgravity (very low forces of gravity) on the bones of their skeleton.

On Earth, the human skeleton is constantly working in opposition to the force of gravity. In outer space, however, the skeleton faces no mechanical load stimulus. As a result of this, the whole process that is natural on Earth does not take place; bone resorption increases while bone formation remains constant or decreases; this causes a loss of bone density. Moreover, bone is made up significantly of calcium. The calcium freed from the bone migrates through the blood and the astronauts may therefore suffer from calcium kidney stones. (Smith et al, 2012)

In addition to the lack of mechanical stimuli, there are several other causes of bone density loss. Microgravity reduces the bodily fluid pressure in the legs which may also contribute to bone density loss in the legs. (Carpenter et al, 2010) Astronauts often experience "gastroparesis", a slowing of the gastric process. The bloated feeling from gastroparesis can cause a reduction in appetite. (Harris et al, 1997) Consequently, if astronauts do not eat properly, they may suffer from a lack of nutrition which can also adversely affect bone density.

A study was conducted in the year 2000 on the astronauts of the Mir Space Station, as well as on astronauts of the International Space Station (ISS). Researchers utilized a Dual-energy x-ray absorptiometry (a DEXA scan), which uses laser beams to measure bone density. The DEXA scan results showed a one percent decrease in bone density at the lumbar vertebrae. Furthermore, there was a greater loss in bone mass density at the hip (1-1.6%). This decrease in bone density can exacerbate the danger of bone fractures. (Carpenter et al, 2010)

Research conducted on astronauts of Skylab IV who stayed in space for eighty-four days analyzed the calcium loss, which indicates bone loss, from their journey. Increasing amounts of calcium were secreted in the astronauts' urine over the duration of the first 30 days, after which the loss leveled off. Additionally, the loss of calcium excreted in defecation continuously increased throughout the journey. Overall, the astronauts lost about 200 mg of calcium a day throughout the mission. (Rambault et al, 1979)

In order to combat bone mass loss by creating artificial mechanical stress, astronauts exercise strapped down to a treadmill. The up-and-down movement of running may cause the body to build new bone. (Chang, 2014) Although exercise may prevent bone mass loss in most of the body, the bones found in the oral cavity cannot be helped by exercise. In fact, jiggling or clenching of the teeth does not cause bone strengthening, but rather bone deterioration in that area. Furthermore, as opposed to long bone loss, which can possibly be reversed upon return to Earth, tooth loss cannot be. (Stenberg, 2001)

In order to prevent excessive bone loss in the oral cavity, as well as the long bones, astronauts are instructed to consume calcium and vitamin D supplements. However, even with the supplements, studies have still shown bone resorption markers in high levels. (Stenberg, 2001)

The bone loss faced by astronauts is almost identical to that faced by sufferers of osteoporosis, a disease that affects many elderly people on Earth. Therefore, drugs commonly used to combat osteoporosis, can be useful to prevent skeletal atrophy during a spaceflight. These drugs are known as bisphosphonates and are marketed under the names of Fosamax, Boniva, Actonel and other brands. They effectively prevent bone resorption, but do not help bone fracture healing. Therefore, anabolics, such as parathyroid hormone treatment may be advisable since it can improve fracture healing. (Carpenter et al, 2010)

Aside from bone density loss, the spine itself is affected by microgravity. The human spine is composed of vertebrae separated by intervertebral discs. On Earth, the discs are compressed due to the effects of gravity. In space, there is no compression and the vertebral column expands up to two inches causing astronauts to actually “grow” taller in space. (Kramer, 2013) The spine’s expansion, however, affects the muscles and ligaments and often causes backaches. (Carpenter et al, 2010) This height boost is only temporary and reverses itself a few months after returning to Earth. Currently, astronauts on the ISS are studying the effects of microgravity on the spinal column using ultrasound scans. (Kramer, 2013)

The lack of gravity also engenders a different problem in the human body. The body is composed of approximately sixty percent water. Normally, gravity shifts majority of the water to the lower part of the body. In space, however, fluids are dispersed equally throughout the body, causing an irregularly high amount of liquid in the upper part of the body and lower than normal in the lower extremities. Therefore, astronauts’ faces appear puffy and their heads actually feel bloated. Internally, the brain is also subjected to higher pressure than normal, due to excessive cerebrospinal fluid. (Chang, 2014) Within the first day in space, an astronaut may experience an upward shift of up to a liter of liquid volume from each leg. (White, 1998)

This upward shift of bodily fluids has both irritating effects and more serious consequences on the human body. The extra fluid in the head blocks the sinuses, causing what is known as “space sniffles.” Astronauts often have stuffed noses throughout their stay in space. (White, 1998)

The upward fluid shift has other more serious ramifications: the body recognizes the excess fluids in the head and face, and responds by attempting to eliminate bodily fluids. Therefore, blood plasma and red blood cell mass are reduced. As a result of the hemolysis or destroyed red blood cells, astronauts often suffer from anemia. Anemia is a condition characterized as the lack of erythrocytes or red blood cells which carry oxygen via hemoglobin throughout the body. (De Santo et al, 2005)

A study was conducted on the astronauts of Gemini IV, who spent around 4 days in space and Gemini V where astronauts spent 7 days in microgravity. Data indicated a decrease of red blood cell mass of 12.2% in Gemini IV and 20% in Gemini V. Plasma volume was reduced in Gemini IV by 8.3% and 6.75% in Gemini V. (De Santo et al, 2005)

Erythropoietin is a hormone that controls erythrocyte production. Therefore, in order to combat the anemia that commonly occurs in microgravity, it would sensible to conduct studies on the usage of erythropoietin. (De Santo et al, 2005)

Another strange impact on the body after exposure to microgravity is that the astronaut’s eyeballs become flattened. Scientists suppose this is yet another result of the excessive cerebrospinal fluid applying pressure to the back of the eyeballs. As a result of the flattened eyeballs, astronauts have reported difficulty seeing things up close while in space; a condition known commonly as farsightedness. (Kramer et al, 2012)

In 2009, Dr. Michael R. Barratt and Dr. Robert B. Thirsk, both astronauts and physicians, noted a difficulty seeing things up close during their six month stay in the ISS. Consequently, the doctors checked each other’s eyes and noticed inflammation in their optic nerves, and scarring on their retinas. NASA is still researching the long term effects of microgravity on the eye, and if the farsightedness is a symptom of even more serious problems. (Chang, 2014)

Another study on astronaut vision problems seems to indicate that the fluid shift from the lower extremities to the upper body is not the sole cause of the vision problems experienced by many astronauts. NASA examined urine and blood samples of twenty astronauts before, during and after their stay in space. The researchers discovered that the astronauts who were experiencing vision problems also displayed lower folate levels preflight and consistently during the flight. This may explain why only certain astronauts face vision problems; the astronauts with a prior deficiency in folate may be more likely to experience a change in eye anatomy and therefore vision changes. This is a theory which requires more study in order to be proven. (Zwart et al, 2012)

It has been long noted that astronauts tend to get sick much more often during and after their spaceflight than normally. In fact, fifteen out of the twenty-nine astronauts who participated in the Apollo program became ill either during or right after their space flight. (Young, 2005) The University of California conducted a study on human immune cells, subjecting them to microgravity. The results proved that T-cells, a vital part of the human immune response, were not activated properly. Normally, when the body discovers an invader, such as a virus or bacteria, it signals ninety-nine genes to turn on which activate T-cells. However, the study found that ninety of the genes did not turn on in the absence of gravity. (Boonyaratanakornkit et al, 2005)

Another major issue faced in space, is radiation and its effects on the body. The Earth is protected from excess radiation by a natural shield known as the atmosphere. The ozone layer, which is found in the stratosphere, absorbs much of the ultraviolet radiation which emanates from the sun. There is also a magnetic field surrounding the Earth which deflects harmful rays. (Setlow, 2003)

In space, where there is no atmosphere, radiation is free to travel. In fact, if an astronaut would stay in space for a year in a low orbiting space vehicle such as the ISS, he/she would receive ten times the amount of radiation that he/she would have received on Earth. And if a solar flare would occur, the radiation risk would be enormously multiplied. An event such as this happened in August of 1972, releasing in just one day one thousand times the radiation that we are exposed to in an entire year on Earth. (White, 1998)

The danger of radiation is that it can cause mutations in DNA, genetic material present in every cell of the body. DNA damage and mutations are often the first of many steps in the carcinogenic process. Therefore, astronauts have an increased risk for the development of tumors and cancer over their lifetimes. In addition to cancer, alterations in the genetic code can cause infertility and sterility, birth defects and stillbirths. (Durante & Cucinotta, 2008)

There are some actions that can decrease the risk of space radiation induced cancers. A diet rich in antioxidants, such as fruits and vegetables, may help prevent cancer. Vitamins A, C and E along with hormones, such as melatonin, superoxide dismutase and phytochemicals from plants such as green tea, are all effective at preventing tumors. Proper shielding on the spaceship, utilizing materials such as polyethylene, may protect astronauts from the radiation. (Durante & Cucinotta, 2008)

The cosmic rays of space can penetrate the spaceship as if there was no barrier and cause some interesting effects. When cosmic rays pass through the retina, they seem to cause the rods and cones, the photoreceptors of the eye, to be stimulated. Therefore, astronauts perceive flashes of light that aren't actually there. This occurs even when they are sleeping, at approximately three minute intervals. Furthermore, the rays can impact the electronic equipment such as laptops and cameras causing them to malfunction. (Atkinson, 2012)

Radiation found in space is different than that on Earth. Celestial radiation is composed of high energy protons and high energy nuclei; terrestrial radiation is made of Y-rays or X-rays. The different rays affect the body differently. Research based on Earth, such as studies of atomic bomb survivors, cannot be applied to astronauts exposed to space radiation. Therefore, it is imperative to conduct more studies on celestial radiation and its impact on the body. (Durante & Cucinotta, 2008)

Another danger facing astronauts due to their exposure to high levels of radiation and high energy particles is the thickening of the ocular lens, a condition known as cataracts. A study was conducted on twenty-one former astronauts and/or cosmonauts, which compared the opacification of their lenses to a control group of approximately four hundred other people of the same age group. Using a Scheimpflug camera system, the study found that the opacity of the lenses in most of the astronauts and cosmonauts was noticeably increased compared with the control. (Rastegar et al, 2002)

On Earth, muscle is strengthened when the body acts against the gravitational pull. Therefore, when an astronaut travels to space, muscle atrophy can begin within five days, and muscles continue to degenerate during the entire stay in space. The degeneration increases the risk of muscles and ligaments tearing. Along with the weakening of muscles, astronauts have noted an increase in muscle twitches and a reduction in fine motor control. (Harrison, 2002)

A study conducted at Brown University School of Medicine analyzed the effects of space travel on muscle fibers. Researchers placed cultured muscle cells aboard the Space Shuttle for several days. The researchers noted that while in space there was a decrease in protein synthesis, while protein decay levels remained normal; naturally, this would result in significant muscle atrophy. When the muscle tissues were brought back to Earth, however, protein synthesis returned to normal levels. Predictably, the lack of gravity was found to be a major cause of decrease in protein synthesis. Interestingly, the scientists discovered other contributing factors to the muscle attenuation, such as reduced levels of growth hormone, anabolic steroids and glucocorticoids. (Vandenburgh et al, 1999)

As a result of this study, scientists delineated steps to be taken in order to avoid muscle atrophy as much as possible, as a result of space travel. First, it was recommended that astronauts exercise regularly in order to build muscle. However, exercise alone was not deemed effective enough. The study showed that injecting anabolic factors or growth hormones, along with the exercise program, would provide a far stronger defense against muscle deterioration. (Vandenburgh et al, 1999)

Research has shown that the lower extremities of the body suffer especially from microgravity. After six months on the ISS, even with an exercise program of treadmill, bicycling and weight lifting, crew members suffered a thirteen percent loss of calf muscle mass. A second study conducted on the ISS crew, proved that spaceflight caused a four to seven percent decrease in thigh muscle mass. Additionally, astronauts lost up to twenty-four percent muscle strength at the knee and four to twenty-two percent at the ankle. Finally, even elbow strength decreased from eight to seventeen percent. (Carpenter et al, 2010)

Cosmonauts Berezovou and Lebedev, who spent two hundred and eleven days on Mir, were impacted so strongly that they were not able to walk off of the spaceship. In fact, the cosmonauts were not able to walk for a week following their flight and needed massive physical therapy in order to return to their muscle tone level before the flight. (Harrison, 2002)

In microgravity, the positioning of the organs in the human body actually shifts. The diaphragm is elevated, as is the liver and the spleen. The heart is correspondingly shifted upward; therefore, a space physician would have to listen for heart beat in a different area of the chest wall than on Earth. (Harris et al, 1997)

Microgravity also negatively impacts the proper functioning of the ear. The human ear is not only used for hearing, but serves an important purpose in assisting balance. The vestibular system is the primary system of the ear responsible for this. Deep in the inner ear is a pretzel-like structure known as the labyrinth. The labyrinth connects to the semicircular canals and otolithic organs, both important in achieving proper balance. The semicircular canals include three loops filled with liquid which convey to the brain when one's head is rotating or moving from side to side. The otolithic organs are comprised of two liquid filled pouches; the brain uses these organs in order to determine the position of the body, such as: standing, sitting, walking, leaning back or lying down. These organs are extremely attuned to the effects of gravity. Therefore, when a person is in a microgravity environment, the vestibular system cannot function properly. This often results in space motion sickness (SMS); symptoms of SMS include imbalance, vomiting, stomach ache, fatigue and irritability. (White, 1998)

Researchers studied the frequency and severity of SMS on astronauts of the Space Shuttle. The study on eighty-five crew member found that fifty-seven (67%) suffered SMS at various levels of severity. Twenty-six astronauts (30%) had a mild case of SMS, while twenty (24%) suffered moderately and eleven (13%) on a severe level. Fascinatingly, there was a disparity in the effect of SMS between men and women. There also seemed to be a significant decrease in SMS severity when an astronaut experienced a second spaceflight. (Davis et al, 1988) Fortunately, most astronauts acclimate to microgravity and symptoms subside after the first few days in space. (White, 1998)

Although many people may be under the impression that the space program has had little impact on their personal lives, they couldn't be farther from the truth. In fact, se College compiled a list of upward of one hundred discoveries or inventions as a result of the NASA space program that directly enhance the lives of the average individual. This list includes everything from microcomputers to new food packaging techniques. Perhaps the most import impact is pertaining to health and medicine; NASA paved the way toward the inventions of ultrasound scanning, MRI, methods of bone analyses and ocular screening techniques, to name just a few. Astronaut Ron Garan has stated: "the ISS provides a unique environment for scientific discovery that simply cannot be duplicated on Earth… it is leading to countless improvements for life on Eearth… [and] enhances our understanding of the human body." (Garan, 2014)

Conclusion

Although humans have traveled and lived in space, even for weeks at a time, outer space still remains an extraordinarily unforgiving and dangerous environment; an alien world that humans are not capable of adapting to. An unprotected human being accidentally exposed to the vacuum of space, would only be conscious for up to eleven seconds or possibly less. Consequently, the body would begin to suffer from paralysis, followed by convulsions, then followed by paralysis again. Then the water of the human tissues would change to water vapor due to the lack of pressure. This would subsequently cause the body to swell enormously, up to double its normal volume. Heart rate might rise initially, but then would rapidly fall. Arterial blood pressure would decrease and blood circulation would cease. (Parker & West, 1973) Undoubtedly, death would shortly follow.

There are some recorded cases of humans who managed to survive very short term exposure to a hard vacuum. In 1966, a technician in Houston was testing a space suit in a chamber that simulated the vacuum of space. Due to a malfunction, he was exposed to the vacuum. In just seconds, he lost consciousness. Fortunately, he was rescued from the chamber within thirty seconds, and he survived. Scientists have experimented with animals, and discovered that no creature has ever survived decompression if exposed longer than ninety seconds. (Roth, 1968)

Robots can do almost anything humans can do, but they do not require food, oxygen or sleep. Robots do not get space sniffles and do not experience SMS. Vision is not impaired by microgravity, nor can it be afflicted by cataracts. Robots cannot be afflicted by skeletal or bone atrophy. It is true that it takes a long time to transmit directions to robots located huge distances away. But even if robotic space exploration is slower than human exploration of alien worlds, it is safe. Today, many researchers even feel that the Apollo project climaxing with Apollo 11's humans on the moon was: "mainly a geopolitical stunt during the Cold War to show American technological superiority over Russia, with science piggybacking on the ride." (Mann, 2012)

The present research supports this argument. The deadly risks of human space exploration way overshadow the benefits. The countless works of fiction depicting voyaging through space, discovering new planets and establishing colonies should remain just what they have always been: works of fiction.

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