Imaging in Space Exploration

I remember the amazement I felt when man walked on the moon. Today, I feel that monies spent on space exploration would be better used in green energy and ocean preservation programs. We already live on earth, the most perfect spaceship of all: Why go beyond it? Regardless of my feelings, space exploration will continue, funded either by governments or private industry. For example, for only US $200,000 (a deposit of $20,000 is required), you can book a suborbital space trip on Virgin Galactic; 340 places are already reserved and paid for.[1] If you want to experience microgravity cheaper, you can go to Las Vegas and fly the "Vomit Comet." If you desire a longer journey, Space Adventures will take you on a 10-day trip to the International Space Station (ISS) for US $25 million, and they even offer flights to the moon.[2] SPACEX is a private company that is nearing completion of its human space transporter, one that NASA will probably use once the Space Shuttle program is grounded.[3] Other private companies developing transporters include Armadillo Aerospace, XCor Lynx, and Blue Origin (owned by Jeff Bezos who is CEO of Amazon). These transporters may also be used for space tourism and for research.

So what happens if we get sick in space? Techniques for conducting physical examinations in microgravity have been studied.[4] These experiments have been done during parabolic flights, space shuttle missions, and longer sojourns at the ISS. During these trips, some gravity is still present because most happen close to earth (micro- or partial gravity environment).[5] For example, in the ISS, gravity is about 88% of that felt at ground level here on earth (astronauts seem to be floating due to the fact that they are traveling at about 17,500 miles per hour). In 1 study, physician-astronauts were asked to evaluate the effects of microgravity on the cardiovascular, musculoskeletal, and neurosensory systems. The evaluation of the latter included only reflexes (which were brisker in space). Head and neck radiologists may be interested in the fact that facial and nasal mucosal swelling are common during space travel (due to fluid redistribution).* The normal flexed position the human body assumes in space may have effects on the spine, and we know that astronauts are taller when they come back from their missions. When arriving back from Mars, it is estimated that bones will have lost nearly 60% of their attenuation (it takes nearly 1 year to recover bone attenuation lost during 1 month in space), so astronauts will be at increased risk for vertebral fractures. Some think that complete bone mass recovery after prolonged space trips is not possible.

Decompression sickness is not uncommon in space and, as we all know, it may affect the brain. Inside a space suit, "atmospheric air" is purged of all nitrogen and replaced completely by oxygen. The pressure inside the suit is about one-third of normal to allow easier breathing and motion. Before an astronaut dons the suit, he or she must go through decompression to eliminate circulating nitrogen, and this is also done when coming out of it. During depressurization, air expands and may result in ear and sinus pain, decreased hearing, and mandible and tooth pain. The inner ear is affected mostly during the first 2 days of a space trip and triggers loss of balance and dizziness. Dizziness and fainting also are caused by orthostatic intolerance. An astronaut's blood volume is reduced by 22%, affecting cerebral blood flow. Sleep disturbances are very common; most space travelers get only about 2 hours of sleep and, to get any, they must take strong sedatives. Alertness is reduced and performance errors are more common, which is typical if you are sleep-deprived. Feelings of isolation, depression, and other emotional disturbances are also typical.

As extraterrestrial trips last longer, 2 critical situations that may affect our nervous systems arise: immune system weakness and exposure to radiation. T-cells do not function normally in space, making individuals more susceptible to infections. Valentin Lebedev, a cosmonaut, spent 221 days in orbit and later lost his eyesight due to cataracts as a consequence of radiation exposure. In one study, 48 cataracts developed in 295 astronauts, particularly those who were on longer missions in Skylab, the Space Shuttle, and the ISS.[6] The cause was probably genetic damage in epithelial cells, disruptions of cell cycles, apoptosis, abnormal differentiation, and cellular disorganization due to exposure to high-energy protons and heavy ions. Because eyesight problems account for 40% of disqualifications in astronaut selection, cumulative radiation exposure plays an important role in recurring space trips. Radiation, particularly cosmic radiation, easily penetrates aluminum, the most commonly used material in space ships. The International Commission on Radiation Protection sets a limit of 20 mSv/year for commercial flight crews.[7] The highest doses of radiation (about 5 mSv/year) in commercial aviation have been registered for Concorde crews. Cosmic radiation becomes a problem with longer missions, and going to Mars will take about 2.5–3 years.

To control radiation exposure, new building materials are being designed and strict monitoring of exposure levels will be needed. It has been estimated that middle-aged astronauts will probably do well as the effects of this exposure will not be evident during their normal life span and probably they are past the age of having children.[8] NASA has set a limit of 6 Sv lifetime skin exposure (though it varies somewhat with age and sex and for specific organs). Exposure of more than 1 Sv/year induces cancer. Exposure to 2–4 Sv/year results in chronic radiation syndrome with complex clinical symptoms. Because cosmic radiation comes in great part from the sun, living in regions exposed to maximum solar activity (such as the moon's South Pole, a proposed place for a refueling station on our way to Mars) may result in high acute single doses. A single exposure between 3 and 5 Sv will most likely kill you due to bone marrow and gastrointestinal syndromes.[9] It may not take long to die from the gastrointestinal syndrome if you vomit inside your space suit (though the ventilation systems in space helmets are designed with this in mind).

Most of these disorders will take place once individuals return to earth, so diagnosing and treating them in the usual fashion will not be a problem as it would in space. However, with space tourism and prolonged space journeys just around the corner, we may need to diagnose and treat some problems in space. For example, under normal gravity conditions, urine

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*This is part of the so-called NASA beauty treatment: redistribution of abdominal organs results in a smaller waistline, facial edema erases wrinkles, and appendages sag less with age. For more about this and other space travel issues, I recommend Mary Roach's *Packing for Mars: The Curious Science of Life in the Void.* New York: WW Norton, 2010.

exerts pressure on the bladder floor resulting in the need to urinate, but in zero gravity, overfilling results in urethral compression and urinary retention. This why astronauts urinate on a "preventive schedule" and know how to catheterize themselves.

Teleassistance in medical conditions leads to 2 situations: evacuate or treat on site. Companies providing telemedicine services to remote sites such as Antarctica and Mount Everest have the option to order evacuation, but in space, we will probably have to treat there (though astronauts in low-altitude missions have been deorbited when sick). Transmitted data now routinely include temperature, pulse oxymetry, electronic stethoscope, graphic files, and videoconferencing. Devices using near-infrared spectroscopy that are capable of monitoring a variety of physiologic parameters are being developed.[10] In space exploration, transmit lags need to be kept in mind (40 minutes from Mars to earth, so any real-time interactions are not possible).

Still, we have learned from the experiences of 23 US physicians who have traveled in space that some treatments up there may be possible. Space health monitoring started in 1961 with Yuri Gagarin (and before that with monkeys). Here we need to remember that at the start of the space programs, we did not know the answers to simple questions: Can the heart beat in space? Can we urinate in space? Can we swallow in space? and so forth. As spaceships became bigger, the possibility to diagnose and treat disorders in space became a reality. The US and Russian space programs estimate 1 emergency in space per year and the requirement for advanced life support and/or anesthesia at once every 3–4 years.[11] For cardiopulmonary resuscitation, several methods of chest compression have been attempted, but none work well in micro- or partial gravity. Intubation has been studied, but it probably takes too long to be of any good. Surgery has only been tried in animals, and collection of any organic materials released is a (big) problem, though drawing blood is feasible and safe. Overall, space crews receive about 40–60 hours of medical training, and, when combined with telemedicine, the quality of care is comparable to that available in an earthbound ambulance.

Evacuations would require a permanently available vehicle or a second constantly orbiting one. Limited space in these vehicles is not optimal for procedures when evacuating an acutely sick individual. Emergency ballistic re-entries can exceed 7*g*, and though humans can perform well in hypergravity conditions, devices such as Ambu bags (Ambu, Copenhagen, Denmark) do not. Radio communications are not possible during re-entry. Nevertheless, evacuations from even the moon may be faster than those from Antarctica during winter. In the 1980s, Soviet cosmonauts performed sonography in space, and in 2004, sonography was used to evaluate the shoulders of astronauts in the ISS. Shoulder evaluation may be needed after strenuous extravehicular activities when astronauts complain of pain. Astronauts received a 5-hour course 4 months before launch and completed a 1-hour enhancement program once on-board the ISS.[12] Examinations took only about 15 minutes, and, when combined with teleguidance, were thought be good enough for decision-making. Sonography in space has also been used to evaluate the heart and the intervertebral disks.[13] Sonography may not be adequate for evaluation of the central nervous system, though it could potentially diagnose abnormal flow in major arteries and then, with focused applications, could be used to enhance fragmenting of clots in patients with stroke.[14]

A NASA project deals with the stability of medications in space.[15] Radiation may alter chemical stability and diminish potency and shelf life, something particularly true of vitamins and amino acids that are essential to maintain a healthy diet on long trips. These experiments may lead to alternate manufacturing, storage, and dispensing methods.

Ideally, larger spaceships could carry CT or even MR imaging scanners. Several teams of investigators are developing CT units that use electron beams guided by magnets and thus have no moving parts. These units could potentially become small enough to be deployed to combat zones and later into space. Optical coherence tomography is being tested in catheters and endoscopes and theoretically could be applied to sonography, CT, and MR imaging. Hand-held MR imaging units may one day be possible as superconducting quantum interference devices improve. A German laboratory has developed a palm-sized magnet capable of 0.7T.[16] A hand-held sonography device that looks almost exactly like an apparatus Dr McCoy used in the *Star Trek* series is available.[17]

In reality, I think that there will be very little, if any, use for neuroimaging in space. If images are generated, we certainly can interpret them down here on earth. That's what I like to think of as the ultimate moonlighting . . . or perhaps "Marslighting."

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M. Castillo
Editor-in-Chief

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