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Commentary

The biomedical implications of living off-Earth

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Not long ago, the prospect of humans living off-Earth seemed like science fiction. In sixty years of human space flight, fewer than 600 people have been to low Earth orbit, and just 12 have stood on the surface of another world. The cost and difficulty of liberating humans from the grip of gravity put dreams of living off-Earth on ice. Yet that is rapidly changing [1]. Space entrepreneurs Elon Musk and Jeff Bezos are perfecting reusable rockets that can ferry people more frequently and cheaply into orbit, and Musk's company Space-X has announced plans for a large rocket to ferry people to Mars. NASA intends to send astronauts to Mars by 2035, and the Chinese also intend to build a lunar colony followed by a Mars colony. It may only be a few decades before colonists are spending their entire lives on another world. While the space program so far has understandably concentrated on physics and engineering challenges, interdisciplinary groups of scholars are now engaging with the ethical and medical situations the colonists will face [2-4]. This commentary summarizes some biomedical implications of living off-Earth, using Mars as the example.

The major challenges for long-term, human existence in space are: (1) the physical effects of exposure to radiation, (2) the impact of reduced gravity, (3) and the demands of working in an isolated environment. Humans already possess an innate ability to adapt to and cope with extreme environments [5-7], and potential colonists will undergo a careful selection process which is likely to magnify these attributes. Radiation can induce carcinogenesis through direct DNA damage and mutation [8] and increase the capacity of the immune system to induce inflammation that causes cellular damage which leads to carcinogenesis. There is also a risk of significant visual impairment from radiation cataracts and changes to cognition and memory [9,10]. Microgravity during space travel causes bone and muscle loss, which affects the overall cardiovascular system overall. These effects can be mitigated by exercise and pharmacological intervention [11,12]. On planets such as Mars, where the gravity level is one third that on Earth, the reduced gravity might no longer provide sufficient loading to maintain bone and muscle integrity, and optimal cardiovascular function [13]. Last, isolation and confinement, especially as experienced by the first explorers and settlers, will have direct psychological consequences of depression, anxiety, and interpersonal conflict, but they can also contribute to degradation in physiological functions such as immunity and cardiovascular functioning [14].

The technological frontier of long-term adaptation to living off-Earth is genetic engineering. This opportunity has been created by the emergence of the field of synthetic biology [15], and more recently by the development of precision gene editing techniques such as CRISPR-Cas9, which can be used for enhancement as well as therapy [16]. Genes have been pinpointed for valuable features such as radiation resistance, extra-strong bones, toleration of low oxygen levels, enhanced memory, and reduced incidence of a range of diseases and medical conditions including atherosclerosis and various cancers [17-18]. While there are substantial ethical issues raised by genetic engineering, in the case of off-Earth colonists it could be argued that its role will be preventive medicine rather than enhancement, since the goal is to enable survival in a harsh and unforgiving environment. The legal and regulatory framework for off-Earth activities is largely undefined, and colonists will probably self-select to be "technology forward," so genetic experimentation should be expected. Synthetic biology pioneer Craig Venter has already suggested that NASA select astronauts based on genetic strengths relevant to their resistance to hazardous factors in space and consider actively engineering the human genome to maximize their suitability for these new environments [19].

One obvious and realistic body modification would be to the vestibular organs of the inner ear, which interact with the other senses to maintain spatial orientation and compensatory reflex responses

[20]. Reduced gravity can lead to disorientation, nausea, ataxia, and motion sickness. While some adaptation does occur, implantable vestibular prostheses have been developed which can replace some of the lost functions [21]. The multiple interacting stressors of space flight can affect the gut microbiome, which consists of fungi, bacteria, and other intestinal microorganisms [22]. Resulting disruptions occur because of interactions of the microbiome with many other body systems, including cognition [23]. A remedy may be an implantable pump used to provide a regular infusion of new microbiome components, similar in principle to probiotic supplements or fecal transplants [24]. A team led by the NASA Ames Research Centre has published a roadmap which includes proposed mechanisms for conferring radiation resistance on astronauts [25]. They also outlined future research directions which include gene therapy with genes known to confer radio-resistance on lower organisms, upregulation of endogenous DNA repair, and isotopic substitution of organic molecules as a further protective mechanism. Molecular targets for human enhancement, such as genes known to play major roles in the development and maintenance of hard tissue, have been identified [26]. To address bone loss due to microgravity, CRISPR and related techniques can be used to enable better bone and muscle regeneration [27].

While gene editing provides internal biological modifications, bioprinting, or the application of 3D printing for biological substrates, provides an external source of biological modifications. The role of tissue engineering and 3D bioprinting in space exploration has recently been reviewed [28]. 3D bioprinters face challenges due to the demands of printing live cells, but there has been success in bioprinting cells, tissues, and organs [29]. Radiation-damaged tissues could be replaced with bioprinted tissues. Combined with induced pluripotent stem cells (where cells from the patient can be reprogrammed into stem cells), it is possible to bioprint tissues that will not cause immune rejection [30-31]. Relevant to bone loss caused by reduced gravity, 3D printing has been used to treat fractures by printing exoskeleton systems to provide structural stability, internal replacement with Titanium skeletal parts, and skeletal scaffolds for stem cells to regrow and mend the break [32-33]. Colonists could benefit from 3D bioprinting of prosthetic limbs and tissue-engineered organs, or an entire exoskeletal structure [34]. At the technological cutting edge, there is recent progress in brain-computer interface communication systems in patients without full movement, or who are unable to communicate after trauma. Algorithms decode neural activity and transfer brain patterns into real-time speech with word error rates as low as 3% [35].

Finally, there are biological implications for the entire off-Earth population. If settlements are restocked with new recruits from Earth, physiological changes will be modest. But subsequent settlers may sever the umbilical; they might be dissidents, driven by utopian ideals, or compelled to by the difficulty of resupply. As the colonists live and die off Earth, their psychological landscape will be sculpted by their new environment. In time, they could evolve into a new offshoot from the human tree. The minimum size of a viable colony to avoid genetic abnormality and inbreeding is about 100 to 150. Effective population and minimum viable population are estimated to be no less than 1,500 and 3,000 to 5,000 respectively [36]. Settlers will be subject to two phenomena well known among small, isolated populations on Earth: the founder effect and genetic drift. A shrunken gene pool has the counterintuitive result of accelerating evolution. Evolution also gets a boost from DNA modification caused by cosmic rays, which – with the combined impact of microgravity – will affect DNA and cause mutations [37]. Conversely, smaller genetic variation has the downside of being less able to respond to new selective pressure. Settlers will be vulnerable to new pathogens that could wipe them out. This becomes a compelling reason for them to engineer and optimize their genetic makeup, augmenting Darwin's natural selection.

Colonists may aggressively adopt technologies for radical life enhancement or for replacing body parts with mechanical equivalents. The merger of man and machine is dystopian to many, but adoption of cyborg technologies will give them power to transcend their physical limitations. This in turn will expand the range of "habitable" off-Earth environments for settlement. This path has its apotheosis in the transhumanist movement [38]. Leading to this speculative vision of the far future. In the radically different and controlled environment of a Mars colony, speciation happens quicker than it does on Earth. Some settlers return to visit Earth thousands of years and hundreds of generations from now. Their language may be unintelligible and their culture unrecognizable, dependent on the intervening level of interaction between Earth and Mars. Given the unstable nature of human culture on Earth and the existential threats we face from weapons, habitat degradation, and pathogens, the settlers might return to a wasted planet devoid of people. They might have evolved to be tall and spindly, with pallid skin, small teeth, and no body hair. Or they may come in an extraordinary variety of forms, since human creativity applied to the new genetic toolbox is likely to flourish, both on Mars and on Earth. It will be unsettling for them, and for us too, like looking into an eerily distorted mirror.

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References

1. Szocik K, Impey CD. Human Enhancement and Mars Settlement – Biological Necessity or Science Fiction? in Human Enhancements in Lunar, Martian, and Future Missions to the Outer Planets, edited by K Szocik. 2019; Geneva, Switzerland: Springer.
2. Szocik K, Abood S, Impey CD, Shelhamer M, Elvis M., Haqq-Misra J, Persson E, Olvideo L, Capova KA, Braddock M, Rappaport MB, Corbally C. Visions of a Martian Future. Futures. 2020;117:102514.
3. Szocik K, Shelhamer M, Braddock M, Cucinotta FA, Impey CD, Worden P, et al. Future Space Missions and Human Enhancement: Medical and Ethical Challenges. Futures. 2021;133:102819.
4. Illardo M, Nielsen R. Human Adaptation to Extreme Environmental Conditions. Current Opinion in Genetics and Development. 2018;53:77-82.
5. Bartone PT, Roland RR, Bartone JV, Krueger GP, Sciarretta AA, Johnsen BH. Human Adaptability for Deep Space Missions: Exploratory Study. Journal of Human Performance in Extreme Environments. 2019;15(1):Article 5.
6. Criscuolo F, Sueur C, Bergouignan A. Human Adaptation to Extreme Space Environment: An Evolutionary Perspective of the Foreseen Planetary Exploration. Frontiers in Public Health. 2020;8:119.
7. Barcellos-Hoff MH, Cucinotta FA. New Tricks for an Old Fox: Impact of TGFβ on the DNA Damage Response and Genomic Stability. Science Signaling. 2014;7:341-345.

8. Cucinotta FA, Manuel F, Jones J, Izsard G, Murray J, Djojonegoro B, Wear M. Space Radiation and Cataracts in Astronauts. Radiation Research. 2001;156:460-466.

9. Cucinotta FA, Durante M. Cancer Risk from Exposure to Galactic Cosmic Rays: Implications for Space Exploration by Human Beings. The Lancet Oncology. 2006;7:431-435.

10. Cavanagh PR, Licata AA, Rice AJ. Exercise and Pharmacological Countermeasures for Bone Loss During Long-Duration Space Flight. Gravitation and Space Biology Bulletin. 2005;18(2):39-58.

11. Kast J, Yu Y, Seubert CN, Wotring VE, Derendorf H. Drugs in Space: Pharmacokinetics and Pharmacodynamics in Astronauts. European Journal of Pharmaceutical Sciences. 2017;109:S2-S8.

12. Hackney KJ, Scott JM, Hanson AM, English KL, Downs ME, Ploutz-Snyder LL. The Astronaut-Athlete: Optimizing Human Performance in Space. The Journal of Strength and Conditioning Research. 2015;29:3531-3545.

13. Palinkas LA. Psychosocial Issues in Long-Term Space Flight: Overview. Gravitational and Space Research. 2007; 14:25-33.

14. Benner SA, Sismour AM. Synthetic Biology. Nature Reviews Genetics. 2005;6:533-543.

15. Gouw, A. Challenging the Therapy/Enhancement Distinction in CRISPR Gene Editing. in The Palgrave Handbook of Philosophy and Public Policy, edited by D Boonin. 2018;493-508. New York, NY: Palgrave Macmillan.

16. Church GM. Multigenic Traits can have Single Gene Variants with Large Impacts. 2019. https://arep.med.harvard.edu/gmc/protect.html

17. Pontin J. The Genetics (and Ethics) of Making Humans Fit for Mars. Wired, 2018. 7 August. https://www.wired.com/story/ideas-jason-pontin-genetic-engineering-for-mars/

18. Gage D. Craig Venter to NASA: Think About Engineering Your Astronauts. 2010. https://xconomy.com/san-francisco/2010/11/03/craig-venter-to-nasa-think-about-engineering-your-astronauts/

19. Goldberg JM, Wilson VJ, Angelaki DE, Cullen KE, Buttner-Ennever J, Fukushima K. The Vestibular System: A Sixth Sense. 2012. Oxford, England: Oxford University Press.

20. Golub JS, Ling L, Nie K, Nowack A, Shepherd SJ, Bierer SM, et al. Prosthetic Implantation of the Human Vestibular System. Otology and Neurotology. 2014;35:136-47.

21. Voorhies AA, Lorenzi HA. The Challenge of Maintaining a Healthy Microbiome During Long-Duration Space Missions. Frontiers in Astronomy and Space Sciences. 2016;3:23.

22. Shreiner AB, Kao JY, Young VB. The Gut Microbiome in Health and in Disease. Current Opinion in Gastroenterology. 2015;31:69-75.

23. Bojanova DP, Bordenstein SR. Fecal Transplants: What is Being Transferred? PLOS Biology. 2016 Jul 12;14(7):e1002503.

24. Cortese F, Klokov D, Osipov A, Stefaniak J, Moskalev A, Schastnaya J, et al. Vive la radiorésistance!: converging research in radiobiology and biogerontology to enhance human radioresistance for deep space exploration and colonization. Oncotarget. 2018 Feb 12;9(18):14692-14722.

25. Braddock, M. Limitations for Extra-Terrestrial Colonisation and Civilization Build and the Potential for Human Enhancements. in edited by K Szocik, Human Enhancements for Space Missions. Lunar, Martian, and Future Missions to Outer Planets. 2020; Cham, Switzerland: Springer.

26. Yuan, J, Tickner J, Mullin BH, Zhao J, Zeng Z, Morahan G, et al. Advanced Genetic Approaches in Discovery and Characterization of Genes Involved with Osteoporosis in Mouse and Human. Frontiers of Genetics. 2019;10:288.

27. Braddock M. Tissue Engineering and Human Regenerative Therapies in Space: Benefits for Earth and Opportunities for Long Term Extra-Terrestrial Exploration. Innovations in Tissue Engineering and Regenerative Medicine. 2019;1(3): ITERM.000512.2019.

28. Thayer P, Martinez H, Gatenholm E. History and Trends of 3D Bioprinting. Methods in Molecular Biology. 2020; 2140:3-18.

29. Alonzo M, AnilKumar S, Roman B, Tasnim N, Joddar B. 3D Bioprinting of Cardiac Tissue and Cardiac Stem Cell Therapy. Translational Research. 2019;211:64-83.

30. Crook JM, Tomaskovic-Crook E. Bioprinting 3D Human Induced Pluripotent Stem Cell Constructs for Multilineage Tissue Engineering and Modeling. Methods in Molecular Biology. 2020;2140:251-258.

31. Maroulakos M, Kamperos G, Tayebi L, Halazonetis D, Ren Y. Applications of 3D Printing on Craniofacial Bone Repair: A Systematic Review. Journal of Dentistry. 2019;80:1-14.

32. Ou YK, Wang WL, Chang HC, Chen CC. Design and Development of a Wearable Exoskeleton System for Stroke Rehabilitation. Healthcare (Basel). 2020 Jan 15;8(1):18.

33. Awad LN, Bae J, O'Donnell K., et al. A Soft Robotic Exosuit Improves Walking in Patients After Stroke. Science Translational Medicine. 2017 Jul 26;9(400):eaai9084.

34. Makin JG, Moses DA, Chang EF. Machine Translation of Cortical Activity to Text with an Encoder–Decoder Framework. Nature Neuroscience. 2020 Apr;23(4):575-582.

35. Smith CM. Estimation of a Genetically Viable Population for Multigenerational Interstellar Voyaging: Review and Data for Project Hyperion. Acta Astronautica. 2014;97:16-29.

36. Moreno-Villanueva M, Wong M, Lu T, Zhang Y, Wu H. Interplay of Space Radiation and Microgravity in DNA Damage and DNA Damage Response. NPJ Microgravity. 2017 May 10;3:14.

37. Bostrom N. Why I Want to Be Transhuman When I Grow Up, in Medical Enhancement and Posthumanity, edited. by B Gordijn and R Chadwick. 2008. New York: Springer, 107-37.