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Commercial spaceflight: Progress and challenges in expanding human access to space

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ABSTRACT

Commercial access to space travel for private individuals is a near-term reality. Compared to the few professional astronauts, cosmonauts, and taikonauts who have flown in space through government programs in the past six decades, the number of these new spaceflight participants (SFPs) will rapidly expand. The SFP cohort will have a much greater age range than traditional astronauts and may also have a much greater prevalence of medical problems. To date, regulation regarding medical screening, certification, or guidelines for suborbital and orbital SFPs has been relegated to the commercial space companies. However, many organizations, ranging from space advocacy groups to academic institutions to the Federal Aviation Administration (FAA), have offered input and recommendations for medical screening of SFPs for the industry's consideration. Simultaneously, governmental space agencies have made progress in defining appropriate preflight medical testing and medical standards and for those commercial providers that plan to provide access to the International Space Station (ISS).

There is limited information available with regard to the effect of spaceflight-related stressors like acceleration, microgravity, and altered atmospheric pressure and breathing gas mixtures on individuals with medical conditions. To date, most research on humans exposed to challenging or extreme environments has focused on a healthy, young, and predominately male population. However, recent studies funded in part by the FAA and conducted by university programs have examined the effect of certain medical problems like cardiovascular disease, diabetes, and back problems in the acceleration environment. While the numbers are small, the early data from these studies examining the effects of acceleration are reassuring.

There is still much for space medicine providers to learn from this new cohort of individuals that will soon be participating in commercial space activities. With appropriate training and treatment or stabilization of medical liabilities, most of those who desire to fly in space will be able to safely accomplish their dream.

1. Introduction

It has long been a dream that the commercial industry could someday provide spaceflight access to the general public outside of government agencies and national programs. Previous space tourism market studies have repeatedly shown the potential market for this type of experience. For example, a report by the Sophron Foundation by Interglobal Space Lines, Inc, in 2000 states that the commercial spaceflight market "offers us an opportunity … attuned to the traditional American values of free enterprise, entrepreneurship, and freedom," as well as the potential "to create not just public jobs, but wealth unimaginable" [1]. Similarly, a report by the Futron Corporation in 2002 declared that there is a "realistic market for public space travel" [2] and even recent projections made in the Federal Aviation Administration (FAA) Commercial Space Transportation 2018 Compendium [3] notes "continued, strong investment in start-up space ventures." Even so, programs promising early human access to suborbital and orbital missions have been frustratingly unsuccessful and transient. Many of the companies that offered promises of vehicle development and tourism flights in the last decade have ceased to operate. While commercial human access to space has been slow, the market remains and the dream of personal spaceflight continues.

Today, several well-funded private companies have made substantial progress and provide some cause for optimism that suborbital and orbital access for paying SFPs may soon become a reality. For suborbital flight, Virgin Galactic, LLC has recently returned to powered flight with their new SpaceShipTwo vehicle, "VSS Unity," and Blue Origin, LLC has demonstrated excellent progress with their suborbital New Shepard vehicle and with the orbital New Glenn vehicle in development. The Boeing Company's Starliner and the Space Exploration Technologies Corporation (SpaceX) Dragon 2 programs are both nearing their first demonstration test flights, supported in part by NASA's Commercial Crew program. Sierra Nevada Corporation's Dream Chaser spacecraft continues development primarily as a cargo vehicle though its original design was intended to carry humans and offer point-to-point cross-range flight.

Still other companies are aiming for an orbital capability, potentially for stand-alone free flight or for ferry rides to and from the ISS. To this end, Bigelow Aerospace has flown a test module to the ISS and has hopes of eventually constructing independent space stations in low-

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Earth orbit. Axiom Space is also working on development of a private commercial space station, and NASA has recently announced that the ISS may be offered for private industry use early in the next decade. Space Adventures, Ltd and the Russian Space Agency (Roscosmos) have flown commercial passengers on eight Soyuz flights to the ISS, and future flights in this private/government partnership may remain an option for some.

Despite the difficulties encountered in gaining access to space through suborbital and orbital spaceflights, it is clear that these flights will soon be available. Those seeking access to these opportunities may be unlike career astronauts, with a much wider age range and with the potential for numerous medical conditions that would preclude a typical spaceflight career. Most of the research data collected to date on individuals exposed to acceleration, hypoxia, microgravity, thermal loading, and other spaceflight stressors have been obtained from a relatively young and healthy cohort. NASA career astronauts undergo extensive medical screening before selection, maintain health through preventive medicine programs, train for years, and are followed longitudinally for psychiatric and other illness. Spaceflight remains medically challenging due to numerous factors, including the risks of altered atmospheric pressure, elevated carbon dioxide, hypoxia, acceleration, temperature extremes, radiation exposure, limited diagnostic and medical treatment options, and remoteness from definitive medical care. Further, for individuals not trained as career astronauts, spaceflight could easily produce significant stress or anxiety from exposure to unfamiliar environmental factors such as confinement, noise, vibration, and reliance upon a vehicle that will be out of the participant's direct control.

Space medicine personnel bear the responsibility to assess the physiological, psychological, operational and environmental stress factors that affect individuals during spaceflights, and to determine the potential negative impact of exposure to those stressors on their health and safety. Because crewmembers are directly responsible for the safety of spaceflight operations (including all space vehicle occupants), the main responsibility of space medicine personnel is to prevent the occurrence of sudden in-flight medical incapacitation or performance impairment among crewmembers. Regarding SFPs, the main responsibility of space medicine practitioners is to prevent in-flight medical emergencies or death among individuals whose health status may vary from clinically normal to diseased. Over the last 20 years, many professional organizations, governmental agencies and special interest groups have proposed medical standards, requirements, or screening criteria to promote the safety of individuals intending to fly in space. In addition, recent studies have sought to understand how SFPs might tolerate the space environment. Here, we will review the history of medical recommendations, mitigation strategies, and the ongoing medical research being conducted to allow safe, enjoyable, and productive flights for SFPs.

2. Evolution of medical recommendations, standards, and guidelines

The human space age began on April 12, 1961 with Yuri Gargarin's flight. Since that time, the vast majority of the more than 500 humans who have flown in space were career astronauts. Astronauts are selected for a unique set of skills but, throughout the history of the space program, each has been required to meet very stringent medical selection criteria [4,5]. Nearly all of the research into human tolerance of the stresses and strains of the aerospace environment has been conducted on young, healthy, and predominately male individuals. Early astronauts were selected in their late 20–30 s and completed their flights by their early 50 s. Weight limits were stringent and general fitness was a requirement for duty.

In contrast, commercial spaceflight opens the space environment to a vastly wider range of individuals who may be younger or older than traditional astronauts, potentially less fit, and may manifest a wide variety of medical conditions. Individual physiological tolerance of spaceflight will depend on the variable challenges of a given mission (suborbital, orbital, lunar, etc.), duty requirements, acceleration profile, time in orbit, cabin environment, landing environment (water vs. land), and any requirement for personal protective equipment (such as parachutes and space suits). In addition, spaceflight is associated with neurovestibular disturbances near launch and entry, red cell and blood volume loss, muscle and cardiovascular deconditioning, bone loss, postural changes, and, in certain crewmembers on long-duration flights, issues with vision changes and potentially elevated intracranial pressure. Decisions regarding medical certification are challenging given that medical care and onboard medical systems will likely be limited. To add to the complexity, there is a paucity of data regarding the effects of acceleration and microgravity on many common medical conditions that may be present in SFPs. Certain progress is being made to reduce the knowledge gap in this area, and recent research is covered in more detail below.

Before the advent of commercial spaceflight, medical standards were developed for the career astronauts. As would be expected, these were very stringent early in the program but, as knowledge of spaceflight medical effects grew, standards were gradually relaxed for the Space Shuttle era given its limitation to low-Earth orbit and short-duration flight. As further comfort was gained, even NASA began to fly non-career astronauts or "payload specialists" to support company-specific payloads or other objectives such as scientific research. Special medical standards created for payload specialists offered even less medical restrictions. Examples of payload specialists include Ulf Merbold and Byron Lichtenberg, who represented the German Space Program on STS-9. Charlie Walker flew as the first non-government individual to serve as a payload specialist for the McDonnell Douglas Corporation onboard three Space Shuttle missions, and Christa McAuliff, who flew aboard the ill-fated Challenger Space Shuttle as part of the "Teacher in Space" program. Others that have flown include politicians, including members of both the U.S. Senate and the U.S. House of Representatives; the Russian space program has similarly flown journalists, political participants, and even paying passengers. While the Challenger accident largely curbed NASA's enthusiasm for flying individuals in space without direct mission-supporting purposes, occasional non-career astronauts still join NASA or international crews for flight.

To address the medical certification of these individuals, spacefaring International Partners (including the Russian Space Agency, NASA, the European Space Agency (ESA), the Japanese Space Agency (JAXA), and the Canadian Space Agency (CSA)) developed separate standards for passengers. These standards are published in ISS Medical Standards Volume C [6], with additional supporting studies and justification published in the medical literature [7]. Passenger standards evolved from career astronaut standards and reflect the qualities needed to ensure mission-success in government missions shared with commercial crewmembers. Final decision regarding medical fitness for flight in government supported programs rests with the governmental space agencies. Even though non-government spaceflight participant standards are stringent, the Russians, NASA, and other International Partners in the ISS have been generous in thoughtfully allowing individuals with medical deficiencies to fly once their conditions were well understood, successfully treated or stabilized, and risk mitigated to an allowable level [8–10]. More recently, the International Partners have published Appendix F to the Medical Standards Volume C [6] that delineates the medical testing needed for medical certification during the Commercial Crew era. In 2012, the FAA and NASA signed an agreement clarifying roles and responsibilities to ensure the safety of individuals who fly on commercial space vehicles. The FAA will license flights of commercial space vehicles carrying civilians; when NASA crews are on board, NASA will continue to certify that flights are safe.

Flight crew and passenger medical certification for suborbital and orbital commercial flights that do not plan to interface with the ISS or

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