LONG DURATION-DEEP SPACE & REMOTE COMMUNITY HEALTH DELIVERY: WHAT IT MEANS FOR CANADA'S EHEALTH LANDSCAPE.

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Abstract

Humans are soon poised to return to the Moon and extend further to Mars but face grave challenges with the mission's success due to the healthcare challenges of such a remote, isolated, and extreme environment. Remote and indigenous communities on Earth face nearly congruent obstacles too – a lack of medical resources, delayed communication, and long transports for evacuation. A previous attempt at solving these challenges via a terrestrial analog of space has provided success and valuable lessons for current and future sustainable iterations of innovation. The current work examines human adaptations to space flight as well as the historical and current telemedicine style initiatives conducted by the National Aeronautics and Space Administration (NASA) and the Canadian Space Agency (CSA). Implementation styles are contrasted, and new insights brought forward for sustainable and meaningful terrestrial collaborations that advance human health on Earth and in long duration-deep space missions. Contrary to an early telemedicine project, new work under partnerships with the CSA has revealed a standard of practice to benefit health in space, on Earth, and in Canada's eHealth Landscape.

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We have this one life to appreciate the grand design of the universe
and for that, I am extremely grateful.

– STEPHEN HAWKING

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List of Abbreviations

CSA	Canadian Space Agency
C^2M^2 or C2M2	Connect Care Medical Module
IHS	Indian Health Service
IMBLMS	Integrated Medical and Behavioural Laboratories and Measurement Systems
ISS	International Space Station
LEO	Low Earth Orbit
LMSC	Lockheed Missiles & Space Company
NASA	National Aeronautics and Space Administration
STARPAHC	Space Technology Applied to Rural Papago Advanced Health Care

Introduction

In February of 2005 NASA published *The New Age of Exploration: NASA's Direction for 2005 and Beyond* a blueprint outlining man's return to the Moon by 2020 (NASA, 2005). Despite the passing of that milestone year, the strategic objectives set forth in "the new age" continue to guide the future of manned space flight. More recently, NASA's *Moon to Mars Strategy and Objectives Development* blueprint (2023) expanded the specific mention of human health from one objective in *The New Age* to seven. The Moon to Mars objectives of human health span three categories of goals from Human and Biological Sciences to Transportation and Habitation, and Mission Operations. Specifically, the themes of these objectives surround (1) understanding human health adaptations in space, (2) creating a system to monitor and maintain crew health autonomy through communication delays and a lack of immediate evacuation, and (3) validating the readiness of such support systems in an exploration-class capacity. Thankfully, a prior report from CSA's Advisory Council on Deep-Space Healthcare has provided guidelines that will propel humanity to explore deep space and go beyond low earth orbit (LEO) once more.

When the first man travelled on orbit around the Earth in 1961 there were countless unknowns. Today, we know how to survive in LEO for well over a year and have travelled a distance exceeding 400,000 km from Earth. But as we prepare to go to the Moon and Mars in the years ahead, we face far greater risks and challenges in maintaining the health and well-being of those aboard. Fortunately, but undoubtedly, the reality is that we do not have to look far to gain insights on the health challenges that have prevented a manned deep space mission. Many remote and indigenous communities on Earth and within Canada face a lack of resources, knowledge, and heavy communication and time delays in seeking emergency treatment –

challenges congruent with long duration and deep space missions (Canadian Space Agency, 2019; Oosterveer & Young, 2015).

The 1961 venture in orbit also recorded biometric data and transmitted it to back to Earth through telemetry linkages, but a more familiar case of medical telecommunication took place in 1959 at the University of Nebraska. Medical professionals there used telephone lines to establish a two-way video consultation for a neurological examine, aiming to provide healthcare to rural communities and facilitate emergency responses (Bauer & Ringel, 1999; Shirzadfar & Lotfi, 2017). Today, and in the past, comparable patient populations receive care and offer guidance, informing space agency use cases and implementations for deep and long duration space flights while innovating telemedicine, eHealth, and health in LEO.

Purpose & Objectives

The aim of this scholarly essay is to delve into the health adaptations that occur in short to long duration space flights and its effects on human anatomy and physiology. It will also examine the historical relationship among telehealth, space exploration, and remote communities. Additionally, it will identify the biomedical challenges faced with long duration and deep space missions concerning health, telehealth, and medical event management. Ultimately, this work will encapsulate Canada's contributions in addressing these challenges, what it means for Canada's eHealth landscape and sustainable health initiatives going forward.

Methods

Implementation of the project will consist of both academic peer reviewed article screenings, and news article and agency documentation in a subjective review strategy. Searches namely explored Google Scholar and PubMed databases for journal articles as well as material published by NASA, the CSA, and other relevant organizations through institution information guides and internet searches. General searches in and outside of databases included terms or phrases such as: human adaptations in space, history of space healthcare / telemedicine / telehealth (and on Earth), remote and indigenous healthcare challenges, deep space healthcare challenges and medical event management. Work for remote and indigenous community healthcare challenges were gathered from a first-hand peer-reviewed account of community member interviews in Canada’s North and circumpolar regions. NASA’s early telemedicine project, STARPAHC, was examined next with agency documentation via its consecutive reporting structure, and lastly, Canadian contributions to space health were assessed via the use of the CSA’s online catalog of published information.

It should be acknowledged however, that the methods for this essay were conducted in a subjective fashion that may be open to hidden biases in the narrative of this work.

Health Adaptations in Space

The human body undergoes many physiological and psychological changes during spaceflight which become measurable and may hamper activities of daily living upon return to Earth. Most notably are sensorimotor, neuromuscular, and cardiovascular adaptations presented to astronauts with impaired gait and balance, a reduction in muscle mass, strength and coordination, as well as cardiovascular deconditioning (Mulavara et al., 2018). Additional psychological and behavioural changes occur too – the isolated, confined, and extreme conditions of space flight offer valuable insight into how future missions and comparable populations on Earth can be studied.

Beginning with neuromuscular and bone adaptations – muscle mass, strength, and coordination, the effects of microgravity heavily impact the physiology of these tissues and systems. On Earth, our bones and muscles are constantly being used to hold ourselves upright when walking or sitting as well as completing tasks of daily living like eating, dressing, and exercising. These activities provide a near constant ground reaction force against our bodies and the work done by our muscles on bone is what helps to regenerate bone tissue, making it stronger. The reduced gravity aboard the International Space Station (ISS) and in space flight results in little ground force and work required by the musculoskeletal system – ultimately resulting in up to 20% of muscle mass loss during short duration flights (NASA, n.d.) and a 2% reduction in bone density per month (Hart, 2019). A 6-month stay in space results in about 20 years of musculoskeletal ageing that would have occurred on Earth (Canadian Space Agency, 2016). Further, 6-months of space travel also results in a 32% reduction in muscular strength (Trappe et al., 2009), similar to a reduction in muscle mass that occurs during periods of bed rest and immobilization on the ground. Currently, in-flight exercise equipment for astronauts has been developed to mimic gravitational loading to try and reduce the atrophy that occurs with space flight. This fact is sure to come into play as we explore longer and in alternative gravitational environments.

Sensorimotor function is impacted by microgravity too. Balance, for example, is largely coordinated from anatomy and physiological mechanisms within the inner ear involving fluid and tiny hairs. The small hairs are set within a membrane and move in relation to the head's orientation and rotational speed. In deep space and on long duration missions the body comes to adapt to the microgravity environment and reinterpret vestibular inputs with a subjective direction of up (Mulavara et al., 2018; Oman et al., 2003). Post-flight there are reduced performances in sensorimotor measures of fine motor control, static and dynamic balance tests, as well as postural stability and agility (Mulavara et al., 2018). Facilitating a quick and smooth transition of the sensorimotor system between gravitational environments especially between two foreign gravities could improve mission efficiency with faster return to normal life on Earth and overall improved astronaut safety.

There are also cardiovascular changes that occur within spaceflight. Blood and fluid redistributions shift from the lower extremities to the head and core causing facial puffiness and increased size and pressures in the brain, eyes, lymphatic system, and spine (Mulavara et al., 2018; Scott et al., 2023). More specifically for cardiovascular functioning, the heart moves from an elliptical to spherical shape in the microgravity environment (Baran et al., 2021). Left ventricle mass atrophies up to 10% during a short duration flight (Perhonen et al., 2001), maximal oxygen uptake is reduced (Scott et al., 2023), arterial stiffness, stroke volume and cardiac output are increased (Baran et al., 2021) – resulting in a reduced ability to regulate blood pressure. Returning to Earth after long duration space missions reveals that 80% of astronauts experience orthostatic intolerance and it is one of the main medical challenges when back on Earth. Orthostatic intolerance is the inability of the body to compensate for the redistribution of blood when going from a sitting (or supine position) to standing (upright). This creates low blood pressure, low venous return of blood to the heart and brain, decreased cardiac output, and an increase of pooling in the legs aided by gravity (Figure 1). Generally, astronauts experience a redistribution of blood and fluids to the core along with overall cardiac deconditioning/atrophy

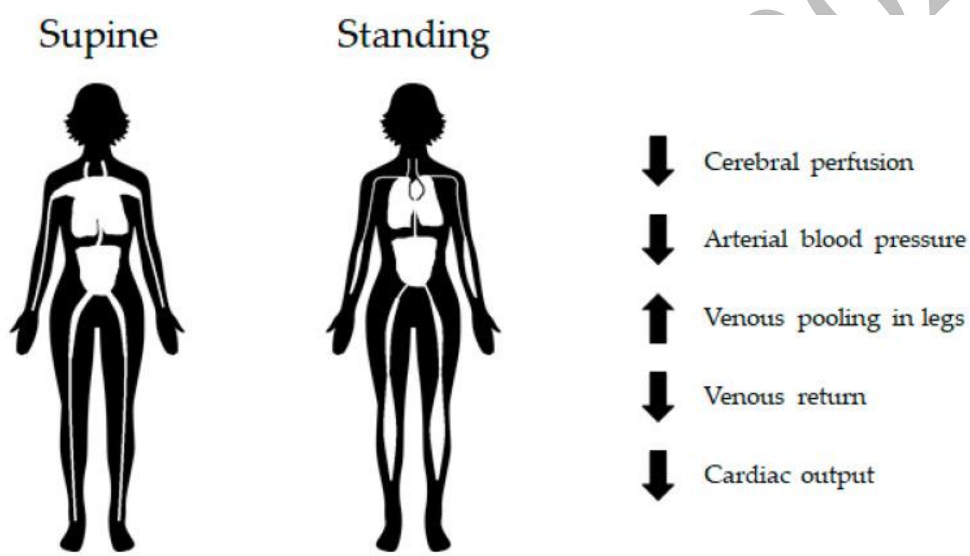


Figure 1: Before and after – blood distribution caused by orthostatic stress on the body. Gravity draws blood downward into the legs and away from the heart and brain resulting in decreased cardiac output and symptoms of nausea, headaches, vomiting, and fatigue. Image sourced from (Baran et al., 2021).

and reduced ability to control variations in blood pressure. The ISS is also equipped with aerobic exercise equipment to encourage vascular maintenance. Some research is even exploring the use of a physical activity video game to encourage astronauts and study their motivation - it has the potential to improve their orbital cardiovascular fitness and provide them with companionship through the long periods of isolation (Samendinger et al., 2020).

Apart from physiological adaptations in LEO and long duration space flights the isolated, confined, and extreme environment far from Earth presents incredible mental challenges to a human being. To begin however, a positive psychological phenomenon occurs to astronauts as they enter LEO and turn to face the window from within their spacecraft. They see the entirety of Earth floating in space with its thin atmosphere, breadth of oceans, and lack of borders. The *Overview Effect* is an experience that engulfs astronauts in wonder and awe, providing them with a sense of connectedness and overcoming of emotion seeing the Earth from this perspective (Yaden et al., 2016). Many astronauts report feelings of unity and come back with a new vision of themselves and the world (Canadian Space Agency, 2022b; Yaden et al., 2016).

Despite the positive psychological affect that spaceflight may provide, the multitude of negatives that it could bring are potentially detrimental to the mission's health. In 1976, Chinese payload specialist Taylor Wang's experiment failed and when denied a rescheduling threatened that he may "not come back" (Slack et al., 2016). Other travelers have created cause for concern with comments about how easy it may be to unlock a docking hatch. One mission in 1976 and another in 1987 were cut short due to psychosocial factors and delusion among the crew members with another crew in 1985 experiencing signs of depression (Slack et al., 2016). Although astronauts are not typical of reporting episodes of depression and anxiety their on-board journal entries well self-report episodes of mild and acute depression more often in longer duration missions (Slack et al., 2016). Astronaut mental health and psychology should be recognized as topics critical to a mission's success – future long-duration and deep exploration class missions should prioritize a harmonious and psychologically healthy crew as the bounds of isolation increase.

The longest duration space flight to date has been 437 days and another reaching an expanse of 400,000 km from Earth – a distance we may soon see again. However, as the limits of manned space exploration continue the risk of behavioural and psychological stressors is likely to rise. Extreme isolation and loneliness, reduced novelty, communication delays from Earth, and the mental burden of a slim rescue could jepordize the future of deep space exploration (Oluwafemi et al., 2021).

Health adaptations in space provide many unique challenges to the current short and longer flight durations present. Particularly impactful in microgravity environments is rapid sensorimotor, neuromuscular, and cardiovascular detriments that occur with hours to days. Not to mention the novelty of adjusting to space, the overview effect is a positive experience for astronauts, however, other negative and potentially mission critical mental and behavioural challenges come with adjusting and living in confined, isolated, and extreme environments. Finding ways to slow the bodies current adapations to space flight and manage these deterierations whilst in space should come alongside understanding preventative medicine and care management on Earth as we move into this new era.

Remote and Indigenous Communities

Populations of indigenous peoples and other communities have lived in remote and far north regions of the planet for thousands of years with the health of such communities maintained by traditional methods and autonomy (Huot et al., 2019). Post colonization, the transition to a more modern way of life has brought increasing burdens of disease and reduced medical care despite the highest healthcare expenditures per capita in Canada (Oosterveer & Young, 2015; Young & Chatwood, 2011). These costs are mainly driven by the transportation of care providers in attending the community as well as patient travel to facilities long distances away. Additional cramped working conditions, understaffing, and high turnover rates contribute to large amounts of task-shifting and further health disparities for those living in remote and indigenous communities (Huot et al., 2019; Oosterveer & Young, 2015; Young & Chatwood, 2011). Overall, these communities lack timely access to primary and non-urgent medical care, preventative programmes, and face increasing burdens of disease while urban areas continue to advance in health and technology.

One research study by Oosterveer & Young (2015) looked at five remote and indigenous communities in the Northwest Territories. The communities ranged in population from 19,000 down to about 140 individuals being only so far south as Yellowknife, and reaching up to the top of the mainland in Tuktoyaktuk (Figure 2). For perspective, Tuktoyaktuk is 1,140 km north of Yellowknife, which is another 1,500 km trip south by road to the nearest urban centre: Edmonton.

Being so far north and remote from large population centers it is as physically difficult to access as it is to attract and retain qualified healthcare service providers. High staff turnover was identified as a main barrier to healthcare accessibility in the Far North with factors such as

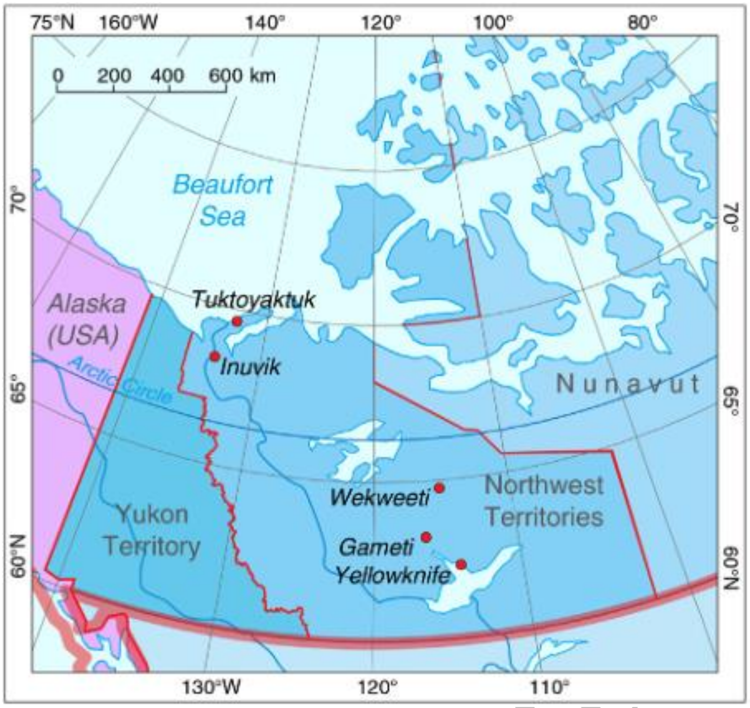


Figure 2: Map of the Northwest Territories with the five communities of study from Oosterveer & Young (2015).

isolation, an extreme environment, and a lack of personal and professional supports contributing to this challenge. In trying to mitigate such staffing challenges, small bursts of overlapping provider coverage create crowded work environments that increase the stress and eventual burnout of practitioners (Huot et al., 2019; Oosterveer & Young, 2015). In their absence, nurses and less qualified community health workers are task-shifted from physicians to cover the responsibilities of primary care. Oosterveer & Young (2015) also examined further studies to find that a lack of training, professional education, and clinical experience influenced the quality-of-care services. Below nurses, community health workers face mounting pressures to prioritize the care of community members they know in care centres with as little as two rooms (Huot et al., 2019). A positive however, reported by out-of-town service providers who work in these communities, is that they received good preparation and training to tackle the stressors that come with broadening their scope of practice in these isolated communities. They stressed the importance of education and preparation courses, as well as having the right supports and a positive attitude to connect with the community (Oosterveer & Young, 2015). Perhaps this lesson could be extended to improve working conditions, reduce feelings of isolation, and boost personal supports to encourage visiting physicians and providers, and subsequently increase the continuity of care in these communities.

As previously mentioned, the distance of the communities from urban population centers studied by Oosterveer & Young (2015) is quite far. In many cases, indigenous and remote communities are solely “fly-in” and may only have the luxury of an ice road in the deep winter months. For when the weather doesn’t cooperate and emergency medicine is required, fly-in communities may have to wait hours or days for a safe mode of transportation to arrive – plus an hours’ long flight to a care centre (Huot et al., 2019). As one community nurse said, “if you had a heart attack here you would never survive” (Oosterveer & Young, 2015). To make things worse, only 18% of small Northwest Territories communities have (largely unreliable) high-speed internet access which make timely instruction via remote consultation or even a simple internet search a time consuming and expensive resource (Krymalowski, 2023). There is no fast route to emergency medical care or quick aid of resolution in remote communities, however, tailored first aid and simulation-based education did help one Northern Ontario community increase their self-confidence in long duration emergency care and patient transportation methods (Orkin et al., 2012).

With a lack of primary care doctors and facilities, 44% of rural living individuals have not seen a family doctor in more than two years because there simply were none available (Rush et al., 2022). These same individuals flock to emergency rooms and walk-in clinics contributing to provider stressors, overcrowding, and increased burdens to the system. Additionally, a lack of preventative supports and discussions (Oosterveer & Young, 2015) also see missed cancer screenings, bone density and blood pressure checks, immunizations and low rates of behavioural and mental health interventions (Rush et al., 2022). Service providers emphasize the rarity of being able to provide preventative care services due to the high workload of acute patients (Oosterveer & Young, 2015) despite it benefits. Most of the residents populating these areas are remote dwellers and First Peoples living with high rates of undiagnosed hypertension, diabetes, COPD, mental health challenges, and obesity (Zhao et al., 2008) – all with minimal community resources. However, the same collaborative life supporting first aid trainings mentioned earlier were also said to have served as a community wellness, education, and physical activity health boost to the local population (King, 2010).

Overall, remote communities in Canada and around the world face tough challenges in providing adequate preventative, primary, and emergency care services. The vast distances of communication and transportation, lack of qualified personnel, and feelings of isolation make health outcomes bleak for residents of northern and rural communities. However, recent works have identified that feelings of connectedness, provider preparedness, and community education in health promotion and medical event management may improve short and long duration health outcomes. Further the expansion and more equitable access to telecommunication networks could be utilized to fill provider gaps within the isolated and extreme environments of indigenous and remote communities on Earth.

Telehealth and Telemedicine in the Space Economy

Telehealth and *telemedicine* are the practice of the delivery of remote non-clinical (telehealth) and clinical care services (telemedicine). Telehealth utilizes telecommunications technology to provide information to health care providers and consumers. Things like administrative meetings, care provider training, and consumer knowledge dissemination are examples of activities that take place under telehealth operations. Telehealth works as a promotive and preventative model of service. On the other hand, telemedicine involves the more clinical and care-centered services that are common in traditional medicine (but from a distance). Tele-consults for chronic disease management, post-operative follow-ups and the general sharing of client charts, lab reports, and prescriptions make up its scope. Together telehealth and telemedicine fall under the more general umbrella of eHealth – combining the disciplines of business, health, and technology. Table 1 displays a comparison of the purposes, services, and scopes of each tele-method where all telemedicine qualifies as telehealth – but not all telehealth being justifiable as telemedicine. Regardless of physical location, the use of data communication, audio, and/or video allows healthcare providers and organizations to interact in real-time with health consumers.

You may have experienced telehealth and telemedicine yourself through the COVID-19 pandemic when telemedicine volumes in the United States increased nearly 50-fold between February and April of 2020 (Vogt et al., 2022). During this time, it allowed society to stay physically distant and safe whilst still being able to receive vital medical services like prescription writing, annual check-ups, diagnoses, and other medical consultations. Though not all medical needs can be met through telecommunications, it does offer a host of benefits and allows care to be delivered where it otherwise may not be possible by physical means.

Table 1: Side-by-side comparison and examples of telehealth vs. telemedicine purpose, services, and scope. Ideas gathered from Disrupt Tech (2022), Fisk et al. (2011), and within this degree.

Telehealth	**Telemedicine**
- Healthcare professional training, consumer, and community education	- Chronic disease management and specialist consults
- Administrative duties	- Sharing client charts, labs, and prescriptions
- Health check-ups and information sharing	- Illness control and remote monitoring
- Wellness from a home and community context	- Institutional context
- Focused on people and self-managed by the user	- Patient-focused lead by clinician or nurse

Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC) Project

Telemedicine began soon after the invention of the telephone and quickly transitioned from basic telephone calls to ingenuity and futuristic visions of radio doctors using two-way video communication. In 1959, "the radio doctor" was realized at the University of the Nebraska when clinicians used video communications to transmit neurological exams of patients across campus to its medical students. Similar data was transmitted during the first human space flight in 1961 to monitor Yuri Gagarin's health. However, due to medical research being "secondary to the engineering objectives of the mission," NASA created the Integrated Medical and Behavioural Laboratories and Measurement Systems (IMBLMS) in 1964 to feed a future in safe long duration missions and mans sustained presence in LEO. The IMBLMS served to measure man's behavioural and physiological attributes during flight and gave astronauts basic medical knowledge where physicians and a fast return to Earth were not possible. At the very least, astronauts would have each other to diagnose and treat. Then, in 1971 a rebooted program was launched with its focus turning to a terrestrial analogue of conditions with a remote population of American Indian's in Arizona (Simpson et al., 2013). The Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC) program sought to improve remote healthcare delivery on Earth and determine the effectiveness, scalability, and gain insights for space flight health systems (*STARPAHC Systems Report. Volume 1*, 1977).

As previously identified, social and physical isolation, medical transportation costs, a lack of qualified service providers, resources, and community training are some of the challenges of remote care delivery on Earth. This new program aimed to combat these challenges with a diverse collaboration of partners each offering their own expertise in the project. NASA served as the program and project management specialist, overseeing technical direction, interagency coordination, contract awarding, data, and document control. The Indian Health Service (IHS) rightfully utilized Indian staff and facilities in the program implementation overseeing healthcare personnel, medical operations management, medical evaluations, and community engagement. Lastly, the biotechnical expert and prime contractor, Lockheed Missiles & Space Company Inc. (LMSC) designed, installed, tested, and trained personnel on computer and software interfaces as well as completed field maintenance and evaluations (Table 2).

The STARPAHC pilot program operationally worked from 1974-77 by utilizing the professional healthcare practitioners of the reserve's hospital to provide medical and technical consultations and direction to field personnel working from remote clinics. Visual, auditory, and the exchange of information between sites utilized telephone lines and radio communications operated by LMSC where NASA oversaw the project implementation and goals.

Table 2: Major responsibilities of the partners involved in the STARPAHC Program. Sourced from (STARPAHC *Systems Report. Volume 1*, 1977).

NASA IMBLMS Program Office	DHEW IHS/Office of R&D	LMSC Biotechnology
Program Management • Program Planning and Budgeting • Technical Direction and Control • Interagency and Contractor Coordination • Program Data and Documentation Control • Government-Furnished Equipment (GFE)	Program Management Team Member • Program and Contractor Guidance and Coordination • GFE, Facilities, Personnel, and Services • Data Base • Medical Operations Management • Interface with Papago Executive Health Staff and Indian Community • Medical evaluation	Prime Contractor • System Definition and Design Responsibility • System Assembly, Test, Installation, Checkout, and Training • Field System Operations and Maintenance; System Evaluation • Computer/Software Interfaces

Functionally, the program operated with a main control centre (the on-reserve hospital), a mobile health unit, and a connection to a larger care centre in Phoenix – for access to specialists. In the control center physicians could monitor vital medical information, access remote controlled television cameras, speak to the patient, and examine x-rays and microscope slides. But perhaps the most important and patient improving aspect of the STARPAHC operation was the mobile health unit. The mobile health unit was a clinical van operated by a driver, a physician's assistant, and a practical nurse that drove on predefined routes and schedules five days a week over the project lands. It was equipped with beginning to end x-ray machinery, an exam room, lavatory, reception area, data entry and retrieval equipment among clinical measurement tools for patient vitals. A visual of the mobile health unit design and attained concept is attached in Appendix 1.

Lessons from the STARPAHC Program

After running a fully implemented telemedicine model with the Papago people for 18-months several key findings and goals were attained. 1) The program increased people's access to medical services; a 19.4% increase in visits occurred with 4.4% more people accessing services – higher than the population growth. 2) Care provider and patients' attitudes changed in favour of telemedicine operations. Physicians valued audio and data communication over video because video was consuming to set-up and less reliable – 96.4% of consults were marked as critical or important for patient care. Community health medics were highly acceptable of the system and appreciated the ease of access to medical consults and electronic medical records. With increased medical confidence in their diagnoses, community health workers noted that it would have been difficult to work alone in such an isolated environment. Patients also valued its convenience and other professionals saw its use for futures in health education and physical therapies.

The next major finding, 3) were the technical aspects of the system. The more trained and experienced a care provider was, the less reliant they were on the need for consults and more confident they were in their abilities. Additionally, engineering design elements of the telecommunications equipment were realized, such as dust control, temperature and humidity monitoring, and a need for sufficient training on equipment and a steady power supply.

The last major lesson learned was, 4) the collaborative nature of the project offered valuable project insights and consulting ideals. Success in its interim reporting structure allowed STARPAHC to continually upgrade its capabilities as innovative technologies were advanced. It identified the need to work with the cultures and languages of the people involved as well as having engineers and physicians dually embedded in the design of equipment and delivery of services. This lesson was importantly beneficial in the 1980's as earthquakes in Mexico City and Soviet Armenia used this telemedicine technology in response to the health emergencies that developed (Simpson et al., 2013).

Overall, the unified goal of improving access to health care in a remote, isolated, and extreme environment on Earth served to bring together interdisciplinary agencies. Government and project management (NASA), the private tech sector (LMSC) and community health organizations (the IHS) combined forces. They each used their own areas of expertise for the research and development of space technologies that served to benefit astronauts on long duration and deep space missions as well as humanitarian crisises after the program's end (*STARPAHC. Part 1*, 1974; *STARPAHC Systems Report. Volume 1*, 1977; *STARPAHC Third Interim Operational Report*, 1977).

Canada's Initial Contributions to Space Medicine

Canada has been involved in the space sector for many years now, beginning with the famous observatory at the University of Toronto in the 19th century, the works of Canadian engineered telecommunications hardware, robotics, biomedical innovations, and physiological experiments have continued to present. Perhaps the most well-known piece of Canadian space innovation is the Canadarm which helped to launch satellites and build the ISS, but an exciting new initiative hopes to make its contribution Canada's flagship piece of work with a transformative approach in healthcare delivery.

The Canadarm is a piece of robotic technology that allows astronauts to perform a variety of tasks vital to spacecraft arrival, departure, and payload manoeuvring. From its multiple decades and iterations in space – made possible by a collaborative operations team, many surgical robotic pieces have come to *spin-off* from this technology. A KidsArm at the Hospital for Sick Children in Toronto performs suturing of blood vessels and tissues ten times faster and with more accuracy than a surgeon (Harbaugh, 2015). The neuroArm was the world's first robot capable of operating and performing brain surgery in an MRI machine (CBC News, 2014), and a subsequent Image-Guided Autonomous Robot was developed for more accurate and less invasive breast cancer biopsies. As of 2018, 30 hospitals across North America were seeing increased procedures and shorter patient recoveries in neurosurgeries from the use of a robotic digital microscope based on the Canadarm 2 technology (Canadian Space Agency, 2018). A direct outcome of technology designed for use in space was the spinning-off of technology for innovations that make life better on Earth.

Various physiological findings such as those involving accelerated arterial stiffing, the advancement of osteoporosis, and cardiovascular deconditioning have helped us understand disease and mitigate the negative effects of aging, bed rest, and even childbirth on Earth (Canadian Space Agency, 2020). Relating to physiological findings is the measurements of such vitals. The CSA and its partners developed the Bio-Monitor, an all-in-one shirt (and snazzy headband) that has the potential to replace the need for several invasive and large medical devices. It has been demonstrated to measure an astronaut's heart activity, blood pressure and breathing rate/volume, skin temperature, blood oxygen saturation, and physical activity levels all as one big wearable device and transmit the data back to Earth (Appendix 2). Meant to replace the need for several large and invasive medical devices it can be worn by astronauts as they move throughout their day for remote sensing by mission control. An additional innovation is a small Bio-Analyzer that has been demonstrated to analyze blood, saliva, and urine samples with just a small sample of fluid. The hope with the Bio-Monitor and Bio-Analyzer is to have their applications expanded to remote communities on Earth to improve cost effectiveness and health outcomes of remote monitoring and telemedicine efforts (Canadian Space Agency, 2021b).

Connected Care Medical Modules

The flagship piece of work mentioned that is currently in the development process is the Connected Care Medical Module, or as the Health Beyond Initiative at the CSA calls them, a C^2M^2. A C^2M^2 will be an all-in-one healthcare enabler that provides space crews with the tools, resources, and empowerment to manage their own health on deep and long duration missions. It is being created with various world partners across industries through a competitive-iterative process focusing on the inequitable remoteness of healthcare and plans to be deployable in a size format like the STARPAHC mobile health unit – in a shipping container. Although the plan for the C^2M^2 is to function autonomously in its environment with medical prevention, diagnostics, and treatment managed by artificial intelligence, its goal is the same as STARPAHC's was 50 years ago. Improving the continuity and quality of care, reducing the patient's physical, psychological, and financial costs of accessing care, and using a terrestrial model of medicine delivery to advance space exploration (Canadian Space Agency, 2021a, 2022a). Beyond the Canadarm, physiological research findings, and C^2M^2, the CSA is also hosting a Deep Space Healthcare Challenge to foster further innovative technologies that increase healthcare autonomy in medically isolated landscapes (Canadian Space Agency, 2021c).

Canada's contributions in the future of space health and healthcare delivery in terrestrial models builds on its historic physiological and robotic contributions to innovation and addresses the obstacles present in remote healthcare delivery. Bringing together industries in collaborative relationships with the focused goal of solving the healthcare challenges of remote and isolated communities is how Canada is contributing to the next generation of care delivery and space exploration.

Discussion

The approach taken to examine the historical relationship between telehealth, space, and remote communities examined work endorsed by NASA, the CSA, and/or conducted by appropriately affiliated institutions to create a picture of how Canada is tackling deep space healthcare challenges along with those facing remote and indigenous communities. It first looked to the extent of the human body's adaptations that occur during short and long duration space flight showcasing the results of exposures to such an extreme environment. Challenges and similarities were drawn from remote and indigenous communities on Earth through a boot on the ground research study and evaluation of NASA's STARPAHC telemedicine program. The present work provides a comprehensive account of the challenges that exist and how Canada, telemedicine, and eHealth can create healthcare that goes beyond terrestrial boundaries.

Physiological Modifications

Reduced function and performance in nearly all physiological systems are affected by exposures to the isolated, remote, and extreme environment experienced during space flight and finding ways to study them is imperative to future space missions. Degraded bone density and muscle mass could render a traveler weak and fragile if it continues past the measured rates in the current durations. Sensorimotor changes and perceived accelerations are altered and persist post flight. Cardiovascular functioning is impacted by reduced oxygen uptake, bodily fluid is redistributed, and arterial stiffness impairs blood pressure regulation. Significantly, on long and short duration space flights these challenges are likely to be exacerbated as the duration and distance of missions increase stressors that can affect medical event management. Continued research of these adaptations while on Earth, from experiments and disease, can help in treating individuals affected and create mitigation strategies on long duration and deep space missions of the future.

Remote Delivery Challenges & a Terrestrial Analog

Astronauts in space are presented with various healthcare delivery challenges and finding a way to reduce its costs while improving its outcomes is imperative to the longer and farther space missions of the near future. Limited personnel and resources, delayed communication, and slow or absent medical evacuations make medical event management and astronaut health autonomy a challenge. Just as the radio doctor had been modeled for nearly 100 years before its adoption in the pandemic, finding an environment to model the remote delivery of health services for space travel should be well modeled before its debut.

Similar costs and limited access to healthcare services are present for remote and Indigenous communities in Canada as well. Long and high transportation costs, a lack of qualified personnel, and unreliable access to technical (including telecommunications) resources drive the inequities of stressful medical events management and low community health autonomy. The significance of the similarities is twofold. Agencies, governments, and researchers can importantly obtain an environment with similar challenges of space and two, better the life and health of communities on Earth with research that is destined for space.

A New Approach to Space Innovation

An eHealth style interdisciplinary undertaking brought telemedicine and remote monitoring to a remote Indian community in Arizona. Specifically, the STARPAHC program brought together three industries: one from health – the IHS, one from technology – LMSC, and one from project and innovation management – NASA. The significance of these three sectors and partners working together under the one unified goal of transferring space technology to the benefit of mankind was that it created a different approach compared to NASA's typical projects. The approach was one of the first to generate technology from the outset with more than an astronaut in mind. It fostered spin-off technologies and strengthened relationships between engineers, community members, and health care practitioners that otherwise may have been slow to develop. Additionally, STARPAHC increased patient access, changed provider and physician attitudes towards the use of telemedicine and remote consultation, and increased community health worker autonomy with the use of telecommunications and electronic health records. The significant culmination of this telemedicine project is that it represents what an eHealth professional is capable of with project management, medical innovation, and awareness of health system challenges.

Canada's Inter-Disciplinary Approach

Canada's very early entry into the space industry and subsequently being a major partner in building the ISS with the Canadarm allowed it to participate in research and set the stage for spin-off surgical uses of its technology. Further, the development of the Bio-Monitor and Bio-Analyzer will significantly allow astronauts to monitor their own health using minimal resources and less invasive methods if proven successful. Such telemedicine techniques have the potential to be applied to remote and indigenous communities on Earth. Improving remote health monitoring capabilities and providing health autonomy in a resource constrained and historically underserved community. These innovations are also highly applicable in other settings requiring telemedicine interventions, such as: elite athletic training, military operations, age-in-place care, and disaster relief efforts.

The C^2M^2 also aims to solve healthcare challenges in remote and indigenous communities by using a predictive and proactive approach that incorporates artificial intelligence into an integrated and scalable system. Significantly, the approach of the C^2M^2 is like the STARPAHC project. It incorporates a multi-disciplinary industry approach and iterative-scalable structure that emphasizes the terrestrial applications and benefits first before envisioning its use in long duration and deep space missions to the Lunar and Martian surfaces. Additionally, its shipping container deployment may increase the rate of health system access by bringing care closer to the patient and reduce the costs and barriers associated with traveling to appointments out of community. However, assuming the standard 8 by 8.5 by 40-foot container, fly-in only communities may face challenges if winter ice-roads are not a possibility and landing areas are insufficient for delivery on aircraft. This is a consideration which is yet to surface in the C^2M^2 project but where the Deep Space Healthcare Challenge may fill the gaps with small telemedicine style innovations. Just like how the Bio-Monitor and Bio-Analyzer are working to solve the challenges caused by a lack of space, long travel times and invasive procedures, terrestrial models could benefit from offline testing/diagnosing, small-modular equipment, and electronic health records.

Most importantly Canada's space physiology research, Canadarm spin-off technology, and work to advance deep space healthcare and medical event management improve the eHealth landscape within Canada. Remote consultations and surgeries with telecommunications will provide thousands of people with timely, efficient, and quality health care services without having to travel far and taxing distances. Healthcare providers can feel confident in boot on the ground staff that have extensive training and practical skills to help reduce provider burnout and alleviate stress in remote, isolated, and extreme environments. The use of artificial intelligence, and attitude change towards the use of telemedicine will provide insights for future change management initiatives in eHealth. Further, project management with an iterative, reflective, and scalable approach will ensure that new technologies are incorporated in a timeline that values collaboration, consultation, and traditional autonomy. And finally, a project like the Health Beyond Initiative with the C^2M^2 and Deep Space Healthcare Challenges will create eHealth extraordinaries fluent in project, change, and data management, engineering design, and health system knowledge that will bring health beyond our imagination.

Limitations and Future Work

Although the current study makes connections to the successes of STARPAHC's feasibility for space health and usage in a terrestrial environment, it does not examine the project beyond its three-year piloting. Following this period, NASA abruptly pulled out of the project. Ensuing technological developments were led without community involvement and represented a lack of appreciation for the main objective – improving the health of remote communities on Earth. Nor were direct health outcomes measured in place of the number of residents that saw increased access to care. Future research should focus on identifying the specific series of events that lead to the end of the STARPAHC program and on the long-term sustainability of innovation projects to develop a framework that guide's future initiatives beyond any piloted timeline. Furthermore, the specific iterations and competitors of the C^2M^2 project should be evaluated and contrasted for their ability to build community and patient autonomy, thereby maximizing space and terrestrial health outcomes.

Another limitation to acknowledge in this piece is the subjective nature of the literature search that could have resulted in inclusion or exclusion biases not stated. Future work should take a systematic approach to journal article screenings to ensure greater scientific rigor.

Conclusion

Today, a new age of space exploration has begun – one that builds on historical space exploration and a century since the emergence of a radio doctor. Current exploration into the historical relationships between telemedicine, space exploration and remote communities has gathered important insights into how Canada is tackling healthcare on deep and long duration space missions. Beginning with research on the physiological adaptations of the human body during short and longer duration space flights, this work highlights the range of medical challenges present in such a unique environment. Further, similarities between space flights and obstacles faced by remote and indigenous communities on Earth has emphasized the need for a more accessible and effective healthcare solution.

Telemedicine evolved as advances in telecommunications provided opportunities for remote care delivery and emergency responsiveness. Its first uses saw medical examinations and the telemetric monitoring of man's first trip to orbit. NASA then developed a novel approach to telemedicine and an interdisciplinary collaboration that produced spin-off technologies, new relationships, and a reshaping of healthcare delivery from a multi-disciplinary perspective. Moreover, it reflects the capabilities of an eHealth professional in driving innovation through project management and a lens of awareness for systemic inequities.

Canada's historical support and contributions to space exploration combined with technologies like the Bio-Monitor, Bio-Analyzer, and Canadarm bring promise to terrestrial applications of healthcare too. By providing astronauts with greater autonomy in monitoring their own health, these innovations are set to transform the patient-provider experience, improve access, reduce costs, and boost the confidence of care for individuals of remote and indigenous communities. Additionally, spin-off use cases are also projected to extend into workplaces, athletics, military operations, and humanitarian crisis management amongst others – ultimately, to the benefit of eHealth with enhanced patient and provider autonomy.

The C^2M^2 project, like that of STARPAHC, showcases a predictive and proactive approach to healthcare case management that aims to determine the effectiveness, scalability, and implementation framework necessary for addressing healthcare challenges in space and in remote communities. The integration of artificial intelligence, prioritization of community engagement and sustainable terrestrial-use will allow for a holistic transformation of healthcare delivery. However, deployment and physical delivery logistics within Canada' northern geography require a more thorough investigation.

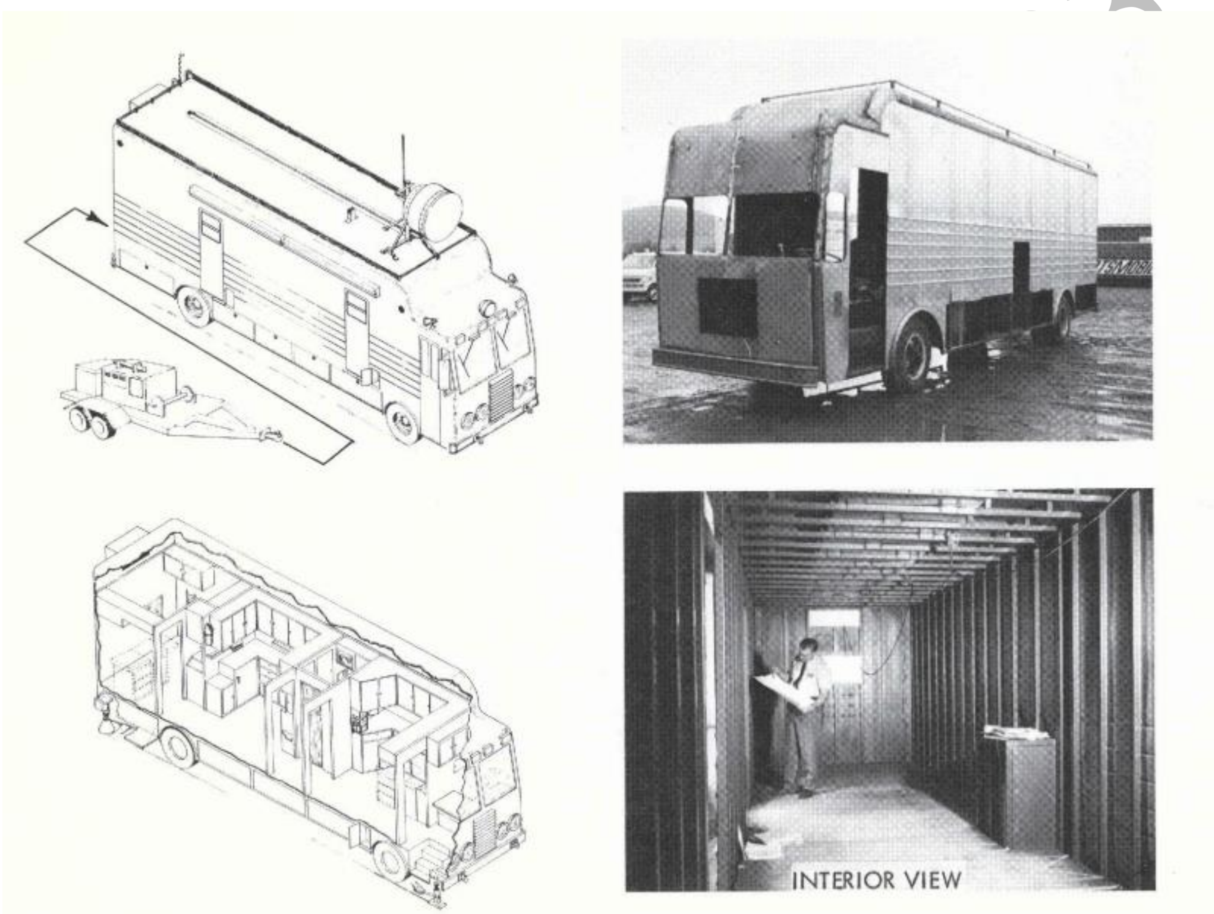
Overall, Canada's space research and healthcare innovations have the potential to advance its role in space exploration and the eHealth landscape. The joining of industries will provide timely, quality, and efficient access of care to thousands of people through tele-visits, electronic records, and mobile clinics. Confident and expertly trained staff knowledgeable in new methods will also help to reduce burnout in such environments. And the embracement of artificial intelligence and an evolving perspective of telemedicine sets the stage for a shift in eHealth change management as spin-off works make their way into terrestrial care delivery.

Undeniably, the advancements of telemedicine and man's desire for exploration has accelerated a reshaping of healthcare delivery, but its sustainability should not be overlooked. Ensuring the stability of any project and especially one like the C^2M^2 telemedicine initiative requires ongoing evaluation, continued community engagement, and a maintained focus on its original objectives to ensure a lasting positive impact. Embracing these challenges with collaborative innovation positions humans and healthcare to reach the Moon, Mars, and beyond.

Appendix 1 – STARPAHC Mobile Health Unit

A drawing of the mobile health unit of the STARPAHC program. It has interior dimensions of 7 ft 6 in. by 7 ft 6 in. by 29 ft long. The top left drawing shows how a trailered power unit would attach behind the van while the bottom left displays the interior layout. In the right two photographs show a skeleton interior and exterior of the mobile health unit.

Image reproduced from (*STARPAHC. Part 1*, 1974).



Appendix 2 – CSA Bio-Monitor

An infographic of the CSA Bio-Monitor made for use of monitoring astronauts health and physical activity levels in space. It has built-in blood oxygen measurements, blood pressure, heart rate and ECG activity monitoring, temperature reading, breathing rate and volume sensing, as well as activity level recording. Being worn by an astronaut the Bio-Monitor continuously collects physiological data and can be transmitted back to Earth upon downloading from the equipment. The CSA hopes to use the Bio-Monitor in medical settings, elite sport training, in strenuous work environments, and for telemedicine in remote communities.

Image reproduced and adapted from (Canadian Space Agency, 2021b).

References

Baran, R., Marchal, S., Garcia Campos, S., Rehnberg, E., Tabury, K., Baselet, B., Wehland, M., Grimm, D., & Baatout, S. (2021). The Cardiovascular System in Space: Focus on In Vivo and In Vitro Studies. *Biomedicines*, *10*(1), 59. https://doi.org/10.3390/biomedicines10010059

Bauer, J. C., & Ringel, M. (1999). *Telemedicine and the Reinvention of Healthcare*. McGraw-Hill. https://books.google.ca/books?id=vrlpAAAAMAAJ

Canadian Space Agency. (2016, July 26). *The TBone studies: Effects of microgravity on astronauts' bones*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/sciences/tbone.asp

Canadian Space Agency. (2018, February 22). *Canadarm2 spinoff technology transforming surgery on Earth*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/iss/canadarm2/canadarm2-spinoff-technology-transforming-surgery-on-earth.asp

Canadian Space Agency. (2019, March 18). *A New Space Space Strategy for Canada*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/publications/space-strategy-for-canada/

Canadian Space Agency. (2020, December 11). *Everday Benefits of Space Exploration: Improving Health Care*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/about/everyday-benefits-of-space-exploration/improving-health-care.asp

Canadian Space Agency. (2021a, May 26). *Astronaut Health Beyond Initiative*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/health/health-beyond-initiative.asp

Canadian Space Agency. (2021b, September 8). *Bio-Monitor: Keeping an eye on Astronauts' Vital Signs*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/sciences/bio-monitor.asp

Canadian Space Agency. (2021c, December 2). *Deep Space Healthcare Challenge*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/health/deep-space-healthcare-challenge.asp

Canadian Space Agency. (2022a, September 21). *Health Beyond's vision for Canadian flagship: Connected Care Medical Module (C2M2)*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/funding-programs/health-beyond-canadian-flagship-c2m2.asp

Canadian Space Agency. (2022b, October 20). *The Overview Effect*. Canadian Space Agency. https://www.asc-csa.gc.ca/eng/youth-educators/toolkits/mental-health-and-isolation/overview-effect.asp

CBC News, C. B. C. (2014, October 2). *Canadarm robotics technology debuts for breast cancer patients*. CBC. https://www.cbc.ca/news/health/canadarm-robotics-technology-performs-breast-cancer-biopsies-1.2785869

Disrupt Tech. (2022, January 27). *Telehealth vs Telemedicine: The Benefits of Telemedicine You should Know About*. https://disruptglobal.com/telehealth-vs-telemedicine-the-benefits-of-telemedicine-you-should-know-about/

Fisk, M., Rudel, D., & R, R. (2011). Definitions of Terms in Telehealth. *Informatica Medica Slovenica*, *16*, 28–46.

Harbaugh, J. (2015, March 27). *Canadian Space Technology to Help Sick Children* [Text]. NASA. http://www.nasa.gov/mission_pages/station/research/news/csa-to-help-sick-children

Hart, D. A. (2019). Influence of Space Environments in System Physiologic and Molecular Integrity: Redefining the Concept of Human Health beyond the Boundary Conditions of Earth. *Journal of Biomedical Science and Engineering*, *12*(8), Article 8. https://doi.org/10.4236/jbise.2019.128031

Huot, S., Ho, H., Ko, A., Lam, S., Tactay, P., MacLachlan, J., & Raanaas, R. K. (2019). Identifying barriers to healthcare delivery and access in the Circumpolar North: Important insights for health professionals. *International Journal of Circumpolar Health*, *78*(1), 1571385. https://doi.org/10.1080/22423982.2019.1571385

King, M. (2010). Chronic Diseases and Mortality in Canadian Aboriginal Peoples: Learning From the Knowledge *This article is part of a joint publication initiative between Preventing Chronic Disease and Chronic Diseases in Canada. Preventing Chronic Disease is the secondary publisher, while Chronic Diseases in Canada is the primary publisher. *Preventing Chronic Disease*, *8*(1), A07.

Krymalowski, S. (2023, March 29). *Bad internet persists in the N.W.T. despite federal commitments to improve service*. CBC. https://www.cbc.ca/news/canada/north/bad-internet-persists-in-the-north-despite-federal-commitments-to-improve-service-1.6794443

Mulavara, A. P., Peters, B. T., Miller, C. A., Kofman, I. S., Reschke, M. F., Taylor, L. C., Lawerence, E. L., Wood, S. J., Laurie, S. S., Lee, S. M. C., Buxton, R. E., May-Phillips, T. R., Stenger, M. B., Ploutz-Snyder, L. L., Ryder, J. W., Feiveson, A. H., & Bloomberg, J. J. (2018). Physiological and Functional Alterations after Spaceflight and Bed Rest. *Medicine and Science in Sports and Exercise*, *50*(9), 1961–1980. https://doi.org/10.1249/MSS.0000000000001615

NASA. (n.d.). *NASA Information: Muscle Atrophy*.

NASA. (2005). *The New Age of Exploration: NASA's Direction for 2005 and Beyond*.

NASA. (2023). *NASA's Moon to Mars Strategy and Ibjectives Development* (NP-2023-03-3115-HQ). https://www.nasa.gov/wp-content/uploads/2023/04/m2m_strategy_and_objectives_development.pdf

Oluwafemi, F. A., Abdelbaki, R., Lai, J. C.-Y., Mora-Almanza, J. G., & Afolayan, E. M. (2021). A review of astronaut mental health in manned missions: Potential interventions for cognitive and mental health challenges. *Life Sciences in Space Research*, *28*, 26–31. https://doi.org/10.1016/j.lssr.2020.12.002

Oman, C., Howard, I., Smith, T., Beall, A., Natapoff, A., Zacher, J., & Jenkin, H. (2003). *The Role of Visual Cues in Microgravity Spatial Orientation*.

Oosterveer, T. M., & Young, T. K. (2015). Primary health care accessibility challenges in remote indigenous communities in Canada's North. *International Journal of Circumpolar Health*, *74*(1), 29576. https://doi.org/10.3402/ijch.v74.29576

Orkin, A., VanderBurgh, D., Born, K., Webster, M., Strickland, S., & Beardy, J. (2012). Where There Is No Paramedic: The Sachigo Lake Wilderness Emergency Response Education Initiative. *PLOS Medicine*, *9*(10), e1001322. https://doi.org/10.1371/journal.pmed.1001322

Perhonen, M. A., Franco, F., Lane, L. D., Buckey, J. C., Blomqvist, C. G., Zerwekh, J. E., Peshock, R. M., Weatherall, P. T., & Levine, B. D. (2001). Cardiac atrophy after bed rest and spaceflight. *Journal of Applied Physiology*, *91*(2), 645–653. https://doi.org/10.1152/jappl.2001.91.2.645

Rush, K. L., Burton, L., Seaton, C. L., Smith, M. A., Li, E. P. H., Ronquillo, C. E., Hasan, K., Davis, S., & Mattei, M. (2022). A cross-sectional study of the preventive health care activities of western Canadian rural-living patients unattached to primary care providers. *Preventive Medicine Reports*, *29*, 101913. https://doi.org/10.1016/j.pmedr.2022.101913

Samendinger, S., Max, E., Feltz, D., & Kerr, N. (2020, January 24). *Back to the Future: The Köhler Motivation Gain in Exergames*. https://doi.org/10.1016/B978-0-12-849867-5.00005-7

Scott, J. M., Feiveson, A. H., English, K. L., Spector, E. R., Sibonga, J. D., Dillon, E. L., Ploutz-Snyder, L., & Everett, M. E. (2023). Effects of exercise countermeasures on multisystem function in long duration spaceflight astronauts. *Npj Microgravity*, *9*(1), Article 1. https://doi.org/10.1038/s41526-023-00256-5

Shirzadfar, H., & Lotfi, F. (2017). The evolution and transformation of telemedicine. *Int J Biosen Bioelectron*, *3*(4), 303–306.

Simpson, A. T., Doarn, C. R., & Garber, S. J. (2013). *A Brief History of NASA's Contributions to Telemedicine*. NASA. https://history.nasa.gov/NASAtelemedicine-briefhistory.pdf

Slack, K. J., Williams, T. J., Schneiderman, J. S., Whitmire, A. M., & Picano, J. J. (2016). Evidence Report: Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders. *NASA*. https://humanresearchroadmap.nasa.gov/Evidence/reports/BMed.pdf

STARPAHC. Part 1: Final Summary Report (NASA-CR-141459). (1974). https://ntrs.nasa.gov/citations/19750007223

STARPAHC Systems Report. Volume 1: Executive Summary (NASA-CR-151578). (1977). https://ntrs.nasa.gov/citations/19780006833

STARPAHC Third Interim Operational Report (NASA-CR-151432). (1977). https://ntrs.nasa.gov/citations/19770019850

Trappe, S., Costill, D., Gallagher, P., Creer, A., Peters, J. R., Evans, H., Riley, D. A., & Fitts, R. H. (2009). Exercise in space: Human skeletal muscle after 6 months aboard the International Space Station. *Journal of Applied Physiology*, *106*(4), 1159–1168. https://doi.org/10.1152/japplphysiol.91578.2008

Vogt, E. L., Welch, B. M., Bunnell, B. E., Barrera, J. F., Paige, S. R., Owens, M., Coffey, P., Diazgranados, N., & Goldman, D. (2022). Quantifying the Impact of COVID-19 on Telemedicine Utilization: Retrospective Observational Study. *Interactive Journal of Medical Research*, *11*(1), e29880. https://doi.org/10.2196/29880

Yaden, D. B., Iwry, J., Slack, K. J., Eichstaedt, J. C., Zhao, Y., Vaillant, G. E., & Newberg, A. B. (2016). The overview effect: Awe and self-transcendent experience in space flight. *Psychology of Consciousness: Theory, Research, and Practice*, *3*(1), 1–11. APA PsycArticles®. https://doi.org/10.1037/cns0000086

Young, T. K., & Chatwood, S. (2011). Health care in the North: What Canada can learn from its circumpolar neighbours. *CMAJ : Canadian Medical Association Journal*, *183*(2), 209–214. https://doi.org/10.1503/cmaj.100948

Zhao, Y., Connors, C., Wright, J., Guthridge, S., & Bailie, R. (2008). Estimating chronic disease prevalence among the remote Aboriginal population of the Northern Territory using multiple data sources. *Australian and New Zealand Journal of Public Health*, *32*(4), 307–313. https://doi.org/10.1111/j.1753-6405.2008.00245.x