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Auteurs: Authors:	Annie Martin, Patrick Sullivan, Catherine Beaudry, Raffi Kuyumjian et Jean-Marc Comtois
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SPACE MEDICINE INNOVATION AND TELEHEALTH CONCEPT IMPLEMENTATION
FOR MEDICAL CARE DURING EXPLORATION-CLASS MISSIONS

Annie MARTIN
École Polytechnique de Montréal (Canada), Canadian Space Agency
annie.martin@polymtl.ca

Patrick SULLIVAN¹, Catherine BEAUDRY², Raffi KUYUMJIAN¹, Jean-Marc COMTOIS¹

Medical care on the International Space Station (ISS) is provided using real-time communication with limited medical data transmission. In the occurrence of an off-nominal medical event, the medical care paradigm employed is „stabilization and transportation“, involving real-time management from ground and immediate return to Earth in the event that the medical contingency could not be resolved in due time in space. In preparation for future missions beyond Low-Earth orbit (LEO), medical concepts of operations are being developed to ensure adequate support for the new mission profiles: increased distance, duration and communication delays, as well as impossibility of emergency returns and limitations in terms of medical equipment availability. The current ISS paradigm of medical care would no longer be adequate due to these new constraints. The Operational Space Medicine group at the Canadian Space Agency (CSA) is looking towards synergies between terrestrial and space medicine concepts for the delivery of medical care to deal with the new challenges of human space exploration as well as to provide benefits to the Canadian population. Remote and rural communities on Earth are, in fact, facing similar problems such as isolation, remoteness to tertiary care centers, resource scarcity, difficult (and expensive) emergency transfers, limited access to physicians and specialists and limited training of medical and nursing staff. There are a number of researchers and organizations, outside the space communities, working in the area of telehealth. They are designing and implementing terrestrial telehealth programs using real-time and store-and-forward techniques to provide isolated populations access to medical care. The cross-fertilization of space-Earth research could provide support for increased spin-off and spin-in effects and stimulate telehealth and space medicine innovations to engage in the new era of human space exploration. This paper will discuss the benefits of space-Earth research projects for the advancement of both terrestrial and space medicine and will use examples of operational space medicine projects conducted at the CSA in areas such as remote training, tele-mentoring and remote control of an ultrasound.

INTRODUCTION

To extend the human presence in outer space, space organizations are pushing the boundaries of knowledge and technology. A number of space agencies are envisioning manned exploration-class missions beyond low-earth orbit (LEO) to destinations such as the Moon, Mars and asteroids. When compared to missions to the International Space Station (ISS), human missions beyond LEO involve a variety of new challenges to ensure crew health, performance and safety such as communication delays, longer duration of travel, and increased exposure to radiation (1). Medical support of crewmembers will progressively shift from a real-time telemedicine paradigm to a medical autonomy concept as distance increases. The purpose of this paper is to

outline a set of space medicine innovations using telehealth concepts and demonstrate links with terrestrial applications. General aspects of future medical systems for space missions beyond LEO will be covered with emphasis on challenges of remote medical care delivery to astronauts. A focus will be drawn on space-Earth research and cross-fertilization as one potential innovation strategies that could drive advances in space medicine and spin-off opportunities.

EXPLORATION-CLASS MISSIONS

Medical care on ISS is provided using real-time communication with the ground, including limited medical data transmission. In the occurrence of an off-nominal medical event, the medical care paradigm

¹ Canadian Space Agency

² École Polytechnique de Montréal, Canada

employed is „stabilization and transportation“, involving real-time management from ground and immediate return to Earth in the event that the medical contingency could not be resolved in due time in space. In preparation for future missions beyond LEO, medical concepts of operations are being developed to ensure adequate support for the new mission profiles: increased distance, duration and communication delays, as well as impossibility of emergency returns and limitations in terms of medical equipment availability (2). The current ISS paradigm of medical care would no longer be adequate due to these new constraints. For exploration-class missions, the primary health care provider will not be the flight surgeon sitting on console; rather, he or she will need to be co-located with the patient on the spacecraft. The role of flight surgeons will be that of advisor, although store-and-forward data communication can be used for additional analyses by the personnel on ground. It is therefore necessary to emphasise the development of the infrastructure and hardware that will allow medical autonomy on the spacecraft (3).

As prevention strategies cannot provide a 100% certainty that no medical contingencies will occur, intelligent medical systems will be required in order to increase the Crew Medical Officer (CMO) capabilities. To this end, the availability of intelligent medical systems will be required to assist the CMO with diagnosis, monitoring, treatment of sick or injured crewmembers and maintenance of CMO clinical skills. Research and development (R&D) activities in space medicine for exploration-class missions include development of new technologies, procedures, preventive strategies and concepts of operations. Despite the shift to a medical autonomy concept of care, the role played by telehealth will remain of great importance as the CMO onboard will not have all the skills and knowledge to deal with every possible medical event. Although it is expected that CMO skills will likely span a number of medical specialties, the exact combination of skills has not yet been determined and will depend on a large part on the mission scenario as well as the capabilities of the medical infrastructure.

TELEHEALTH

Telehealth refers to the use of information and communication technology for the delivery of health-related services over small or large distances. A typical example of a telehealth application is that of a

healthcare professional located in a remote community requesting assistance from a medical specialist located elsewhere. Videoconferencing systems are commonly used with additional telemedicine tools allowing the transfer of image, video, sound and other types of data, what is generally referred to as real-time telemedicine. This certainly allows for immediate intervention but it is more costly, requires specific technologies and needs higher communication bandwidth. The second type of telemedicine protocol is store-and-forward, in which patient information and data are transferred by email to a specialist for advice. This involves cases which do not require immediate assistance and live data stream.

Although the terrestrial real-time telemedicine paradigm may apply to low-earth orbit missions and even to missions to the moon, communication delays during exploration-class missions will be such that effective real-time interactions will be impossible (2). Telehealth is nevertheless the bridge to medical autonomy. Store-and-forward telemedicine will be the primary method to communicate crew medical information to the ground. In support to the CMO, and in the absence of communication with ground, smart technologies and decision support capabilities will reinforce the concept of medical autonomy to allow timely medical intervention (2). The application of telehealth concepts for exploration-class missions involve the development of methods to acquire, transmit and analyze medical data. Telehealth applications can cover a broad range of tele-consultations: tele-dermatology, tele-psychiatry, tele-readaptation, tele-cardiology, etc. Training and detailed procedures coupled with adequate technologies will allow remote consultants to support the CMO in the medical monitoring of the crew in a variety of medical disciplines as well as for delivery of care.

SPACE-EARTH RESEARCH

There are many areas of common interest between the space and terrestrial medicine sectors and especially with regards to medical care delivery in remote and isolated areas. Similarities between the needs in terms of medical infrastructure for exploration-class missions and remote and rural communities are numerous: resource constraints, lack of real-time support, difficult, impossible or expensive emergency transfers, as well as limited medical training capabilities (4-5). Telehealth technologies and concepts are applicable for space and terrestrial settings; projects including objectives

overlapping the two sectors can double their impact. In order to improve the technology transfer from one sector to the other, both the terrestrial and the space medicine communities would benefit from collaboration based on common interests. The interests that will be discussed in this paper are access to care, medical simulation and medical autonomy.

Access to care

Access to standardized care in remote and isolated areas is complex due to the often insufficient resources on-site. In terrestrial settings, transfer of a patient to specialized centers comes with significant cost and involves also physical and psychological stresses on the patient (4). Similar drawbacks will occur if an emergency return causes astronauts to abort a mission due to serious medical contingencies. In order to facilitate the management of an ill or injured patient/crewmember, technologies and procedures can be developed to allow the medical personnel on-site to manage the situation. Telementoring and remote control of medical devices are two examples that could provide additional benefits to telemedicine tools already being used.

Telementoring

Medical training for CMOs on exploration-class missions will likely be limited due to the multitude of skill sets (nonmedical and medical) for which training is required as well as the time constraints prior to a mission. The CMO would not be an expert in all medical skills potentially needed resulting in the requirement of expert guidance from the ground for medical contingencies that cannot be autonomously managed by the crew. Telementoring of medical procedures is one potential solution when the crew needs such assistance. Telementoring consists of a physician/expert guiding the CMO or another crewmember through a medical procedure. Depending on the mission phase (outbound, onsite, return) and the communications delay, ground support may be provided real-time to assist the CMO. When communication delays impair real-time communication, the medical support from the ground becomes asynchronous and guidance from the ground would be provided to the crew in a store-and-forward fashion. In the case of a time critical event, the medical care paradigm shifts from advanced telemedicine to medical autonomy

Remote control of ultrasound

Ultrasound is currently the only imaging device onboard the ISS and this may also be the case for missions beyond LEO. Ultrasonography is a medical specialty that typically requires extensive training, which the CMO may not necessarily have received during their medical training. To overcome this limitation, remote control of an ultrasound machine is foreseen as a means to facilitate the use of ultrasound during telementoring session. While the non expert is manipulating the probe, the tele-mentor guides the non-expert while at the same time controls the ultrasound machine functions. A graphic user interface (GUI) is currently being developed and will be evaluated to assess the feasibility of remote control of ultrasound's parameters (e.g. gain, depth). There are interesting overlaps between this remote ultrasound project and terrestrial needs. As ultrasonographer visits to remote and rural communities can be infrequent, a remote control capability could help to avoiding expensive patient transfers.

Medical simulation

Medical training and simulation technologies will be critical for exploration-class space missions due to the normal attrition of medical knowledge and skills expected during long periods of disuse during exploration-class missions. Medical simulation would not only allow for continued refreshing of medical knowledge and skills, but could also allow for the acquisition of new knowledge and skills when necessary. Simulation technologies will be critical in the training of complex medical procedures, the assessment of skills acquisition, the testing and validation of new medical protocols in-orbit, the coordination and management of both on-orbit and ground-based medical teams as well as the management of medical resources and consumables. Physicians in rural areas are facing similar problems. Medical simulations and tele-education in a terrestrial setting can provide continuing education as well as allow for more frequent communication with their colleagues to reduce the negative impacts of isolation.

Medical autonomy

Although medical selection of the crew is the first line of defence in mitigating against medical contingencies, medical preparedness is the second line of defence.

This will rely on preparing for increased medical autonomy than currently available on the ISS including the provision of intelligent medical systems for diagnosis, monitoring, treatment and maintenance of clinical skill sets (3).

Clinical decision support system

A space medicine decision support system (SMDSS) is another technology that could assist the CMO in the medical care delivery to the crew. Innovative and intelligent sensor technologies coupled with computer-based analysis could be used to evaluate the risks of developing medical conditions as well as provide clinical support to the CMO in terms of diagnostic and treatment plans. Environmental and biomedical data could be captured routinely and analysed continuously. Should specific trends be identified, recommendations could be generated to optimize the wellbeing of each crewmember and the crew as a whole. In the event of a medical emergency, biomedical data as well as clinical and laboratory findings would be captured to generate provisional differential diagnosis. Crew medical information would be fed real-time to the CMO and in a time delayed fashion (due to communication delays) to MCC in support of the CMO. Activities in line with this involve elaboration of system's requirements such as database structure, inference engine and clinical guidelines. The complexity of such system is challenging. Terrestrial settings could also benefit from such medical systems as this could provide physicians with more information and could support the decision-making process. Beside technological challenges, ethical and legal issues must be investigated to ensure data integrity, security and user acceptance.

Smart sensors

Patient monitoring capabilities will provide the CMO with crew physiological data to perform routine health assessments. These data would also feed an SMDSS database. Communication of data to ground personnel will improve situational awareness and the ability to remotely manage and/or monitor a sick or injured crew member. The "smart" component could involve real-time analysis of signals, alerts and some diagnostic capabilities. One example of an existing smart medical technology is the electrocardiogram system measuring cardiac activity, with embedded software able to diagnose arrhythmia. In terms of space medicine applications, medical sensors will need to be designed to meet space exploration requirements such as lightweight, miniaturized, portable, wireless, reusable, ruggedized, non- or minimally-invasive, user-friendly,

scalable and flexible in their use. Medical device requirements on Earth are certainly not as restrictive but certain situations might require a sub-set of these characteristics. Space medicine hardware could find applications for expeditions, military settings, sports, submarine, etc.

Innovation challenges

The concept of Space-Earth R&D is being reinforced to deal with the challenges of technology transfer from space to Earth. This transfer in the field of medicine is sometimes quite complex due to specific characteristics of both the space and the medical device industry. On the one hand, regulations and technology adoption pathways in the medical care sector are very specific and cannot use regular industrial approaches for commercialization, entry to market and user adoption (6). On the other hand, the space industry is also different from other industrial sectors due to the important role played by the government, the difficulty of access to space, and the inherent risks of space projects (7). These elements prevent us from using common strategy for dual-use technology development.

Space-Earth R&D involves collaboration between organisations. The work in silos in many departments as well as the lack of communication amongst them often prevents utilization of innovations to their full extent and across disciplines. The triple-helix paradigm promoting collaboration between government, industry and academia is getting more attention from decision-makers as this concept emphasizes the advantages gained by participating organisations (8). Space-Earth R&D in the fields of space and terrestrial medicine would benefit from the expertise of universities, private enterprises and government initiatives. Further work is required to evaluate strategies and mechanisms to maximize this approach in the context of space and terrestrial medicine.

IMPACTS MEASUREMENT

To fully understand the outputs of Space-Earth R&D in addressing space and terrestrial problems, the assessment of technology transfer mechanisms, collaborations and socioeconomic impacts is mandatory and will be undertaken. Governments do not only want to stimulate innovation and economic growth, they are also responsible for developing programs to improve people's lives. Social, economic and technological impacts can therefore be measured to understand the

outcomes of public and private investments in science and technology. The methodology to do so in space medicine will involve network analysis, case studies and interviews/questionnaires with decision-makers in private and public organisations. A network analysis will include bibliometric data as well as information on grants and contracts. This will allow an understanding of the collaboration process as well as the role of the Canadian Space Agency in the space medicine innovation scheme. The cross-fertilization of space-Earth research will be evaluated looking at success rate and profits generated from projects between organisations pursuing similar objectives for different applications. In addition, case studies will look at specific projects to improve the understanding of the innovation and collaboration mechanisms in the space sector. This will also provide valuable information in the measurements of socioeconomic and technological impacts of space medicine projects for Canadians.

CONCLUSION

The development of telehealth and medical autonomy paradigms for space exploration, coupled with a coordinated investment in protocols and technologies, could lead to important developments toward improved access to health care and a more uniform standard of care especially in remote and isolated regions. Space medicine innovations for future exploration-class missions will result from the development of the telehealth applications of today. It is therefore realistic to expect that R&D for the development of intelligent medical systems will benefit both the terrestrial telemedicine paradigm and the medical autonomy paradigm for space. Cooperation among government departments, academia and industry in the medical care sector could therefore foster excellence and innovation.

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