Exercise Countermeasures on ISS: Summary and Future Directions

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INTRODUCTION: The first decade of the International Space Station Program (ISS) yielded a wealth of knowledge regarding the health and performance of crewmembers living in microgravity for extended periods of time. The exercise countermeasures hardware suite evolved during the last decade to provide enhanced capabilities that were previously unavailable to support human spaceflight, resulting in attenuation of cardiovascular, muscle, and bone deconditioning. The ability to protect crew and complete mission tasks in the autonomous exploration environment will be a critical component of any decision to proceed with manned exploration initiatives.The next decade of ISS habitation promises to be a period of great scientific utilization that will yield both the tools and technologies required to safely explore the solar system. Leading countermeasure candidates for exploration class missions must be studied methodically on ISS over the next decade to ensure protocols and systems are highly efficient, effective, and validated. Lessons learned from the ISS experience to date are being applied to the future, and international cooperation enables us to maximize this exceptional research laboratory.

KEYWORDS: Microgravity, exercise countermeasures.

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The first decade of the International Space Station Program (ISS) yielded a wealth of knowledge regarding the health and performance of crewmembers living in microgravity for extended periods of time. The exercise countermeasures hardware suite evolved during the last decade to provide enhanced capabilities that were previously unavailable to support human spaceflight, resulting in attenuation of cardiovascular, muscle, and bone deconditioning.

The advanced resistive exercise device (ARED) replaced the interim resistive exercise device (iRED) in 2008, providing far greater load challenge, improved eccentric:concentric ratios, and selection of additional whole body and single joint exercise motions. Both the ARED and iRED offered skeletal muscle strength and endurance never before available on any space vehicle. Shortly thereafter, the second generation treadmill (T2) was deployed to the ISS, replacing the treadmill with vibration stabilization (TVIS), which expanded the exercise countermeasures capabilities by increasing maximum running speed along with the capability to collect ground reaction force data. The European Space Agency (ESA) provided the portable pulmonary function system (PPFS), which significantly improved physiological monitoring capabilities. The recently deployed Russian BD2 treadmill further improved locomotor exerciser potential within the ISS countermeasure suite. Improved heart rate monitoring hardware has been deployed for use with the cycle and treadmill protocols. ESA's subject load system, which is planned for use on ISS later in 2016, will enhance the capability for higher subject loading during treadmill exercise. These enhanced exercise countermeasure and monitoring capabilities offer a tremendous opportunity to evaluate novel exercise hardware and protocols and maximize use of the ISS through 2020 as a multidisciplinary research platform.

NASA's Human Research Program (HRP) was chartered in 2005 with the primary objectives being to conduct research that quantifies the human health and performance risks associated with human exploration missions, and to validate countermeasures and technologies that prevent or mitigate adverse outcomes of these risks. The HRP currently maintains "roadmaps" designed to resolve over 25 health risks. The overall process requires correlating data from in-flight medical operational

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exercise sessions and periodic fitness evaluations with research findings. All ISS International Partner agencies have been charged with the responsibility to collaborate in the characterization and mitigation of adverse crew health issues associated with prolonged microgravity exposure. Each agency has a vigorous program of ground analog and spaceflight studies in progress.

Although the expanded ISS exercise countermeasure suite has resulted in decreased post-mission decrements in crew health, findings from the first decade of ISS habitation have been highly variable due to a multitude of factors, including: exercise hardware reliability; use of exercise protocols that were tailored to address crew needs and preferences; differences in exercise countermeasure emphasis among International Partner agencies; complexities associated with utilization of non-exercise interventions (e.g., pharmaceuticals and nutrition countermeasures); relatively low total number of crew who have resided on the ISS; competition among research studies for crew time; and uncontrollable factors such as anthropometrics, age, and gender. For these reasons, it is imperative that International Partner agencies collaborate and share focused research and longitudinal medical data sets to reveal crew health trends, further improve exercise countermeasure protocols, and optimize crew health and performance. These efforts are "a work in progress" and are essential if we are to maximize outcomes given the limited ISS resources. Finally, while the exercise capabilities have improved on the ISS compared to previous space platforms, the monitoring of simple parameters such as exercise heart rate and resistive exercise ground-reaction forces has proven to be far more complex and challenging than anticipated. This is due to many factors, including the electromagnetic interference environment on the ISS, engineering specifications for spaceflight hardware (e.g., vibration isolation, materials limitations, advanced lead time necessary to certify and fly hardware, etc.), and limited resources available to troubleshoot exercise hardware issues in a timely fashion. Engineering, medical, and research communities must collaborate and address these issues by applying lessons learned from the ISS to next generation monitoring and data acquisition systems.

The parameters of future exploration space missions, including transit and surface time, vehicle and habitat resources, intravehicular and extravehicular physical constraints, gravitational field exposure, and access to Earth-based communication and monitoring, will dictate the countermeasure needs of these crews. These requirements should drive ISS-based research while this platform is still available to us. Requirements for protection of crewmember strength, power, endurance, orthostatic control, flexibility, bone integrity, and neurovestibular health will inform the countermeasure hardware and protocols necessary to enable completion of astronaut critical mission tasks. Critical mission tasks may be planned (i.e., habitat deployment or surface planetary activities) or off-nominal, such as emergency egress of an incapacitated crewmember after landing. Several planned or current ISS research studies will reveal how exploration mission tasks map to physiological performance capabilities, which in turn will guide future countermeasure requirements. The ability to protect crew and complete mission tasks in the autonomous exploration environment will be a critical component of any decision to proceed with manned exploration initiatives.

The next decade of ISS habitation promises to be a period of great scientific utilization that will yield both the tools and technologies required to safely explore the solar system. Leading countermeasure candidates for exploration class missions must be studied methodically on ISS over the next decade to ensure protocols and systems are highly efficient, effective, and validated. Lessons learned from the ISS experience to date are being applied to the future, and international cooperation enables us to maximize this exceptional research laboratory.

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