Physical exercise is the most important countermeasure currently used on the International Space Station (ISS) to mitigate muscle atrophy and bone loss, and to maintain cardiopulmonary function capacity. On ISS, assessment of health status is determined from a Periodic Fitness Evaluation (PFE) conducted starting on flight day 14 and every 30 days thereafter until the completion of the missions. This medical requirement is described in document, MR080L, Cardiovascular Physical Fitness Evaluation: Cycle Ergometry. Another medical requirement is certification for extravehicular activity (EVA). This test is conducted two weeks prior to a scheduled EVA. The test using arm cycle ergometry is described in document MR038L. In both tests, heart rate response in relation to ergometer workload is used to assess physical work capacity. However, the PFE calls for the measurement of oxygen uptake to assess aerobic capacity. Presently, the requirement for metabolism gas analysis is waived due to limitations of the equipment.
Task Description:

However, new technologies using near infrared spectroscopy (NIRS) to determine muscle oxygenation levels may provide a simple and straightforward measure of aerobic capacity. Thus, the goal of this project is to evaluate a new NIRS monitoring device for the assessment of crew health and performance capacities. Near infrared spectroscopy (NIRS) can be used to simultaneously and continuously measure tissue oxygenation parameters, including muscle oxygen tension (PO2) and muscle pH. These parameters can be measured noninvasively on specific muscles to continually assess muscle metabolism during exercise. Previous studies indicate that oxygen consumption, which is traditionally measured with a metabolic gas analyzer, can be calculated from near infrared spectra. This project will investigate the relationship between whole-body oxygen uptake and local tissue muscle oxygenation. The findings may allow reassessment of the need for metabolic gas analysis during the periodic fitness evaluation, and the use of heart rate during arm ergometry testing for certification of EVA. The device might also provide a quantitative assessment of pre-EVA hand-grip strength (MR081L, Physical Fitness Evaluation: Handgrip Dynamometry) where no metric currently exists.

The first NIRS sensor that was developed was used to study muscle oxygenation responses during exhaustive rhythmic handgrip dynamometry exercise. Preliminary evaluation of on-going data collection suggests that the exercise protocol that we are using may be sensitive enough to detect changes muscle oxygenation patterns between endurance and strength-trained athletes.

Rationale for HRP Directed Research:

The metabolic sensor developed as part of this project and our other NSBRI project ("Noninvasive Measurement of Blood and Tissue Chemistry") as earth applications in critical care medicine, exercise physiology, sports medicine, and rehabilitation. This Space Medicine Project is aimed at the last 3 applications. Both aerobic fitness and muscle strength are lost during long periods of immobility, whether they be in space, or as a result of bed-confining illness. The sensors developed in this project are expected to be able to noninvasively assess loss of fitness and improvement in strength and aerobic capacity as a result of training or rehabilitation. The regular measurement of lactate threshold is a very common training technique for high performance, as well as “weekend” athletes. The noninvasive measurement of muscle pH as a surrogate for measuring lactate with a blood sample would revolutionize training by allowing continuous, noninvasive measurement throughout exercise.

Research Impact/Earth Benefits:

This year we worked on protocols for handgrip exercise and cycle ergometry. There was significant progress in both areas.

Handgrip Exercise to Assess Fitness for EVA Tasks

We completed one study of 10 subjects, each of whom performed 9 different handgrip protocols. The objective was to identify the protocol, which could be completed in less than 5 minutes, yet reliably tested handgrip strength. As a result of this study, we selected a test of 4 sec contraction, with 2 sec relaxation at 40% mean voluntary contraction (MVC) for further evaluation. We collected spectra during this study and found some subjects were not measured properly. The spectroscopic problem was identified and fixed.

We began a second study to (1) test the reliability of the 4/2, 40% MVC protocol and (2) determine if subject response during this protocol allowed us to distinguish between trained and untrained subjects. This study was planned for 40 subjects. At this time, 18 subjects have been completed and data analysis is underway. The “trained” group was to consist of rock climbers, but it has been difficult to find rock climbers to participate in the study.

Cycle Ergometry

We completed a laboratory study at UMMs where we validated the new leg NIRS system against femoral venous blood. We also designed and built a new sensor holding mechanism to allow collection of spectra from the leg while cycling, without motion artifacts distorting the spectra. This was successfully tested and shipped to JSC for the leg pilot study, along with the new leg measurement system. We completed 10 subjects in a pilot cycling test where we used the NIRS system to measure muscle PO2, muscle oxygen saturation (SmO2), muscle pH, and hematocrit, along with the metabolic cart to measure oxygen uptake (VO2) and blood to measure lactate. We developed a method of using only spectroscopically measured parameters to calculate a relative measure of VO2. This measurement was well correlated with VO2 determined with the metabolic cart (R2=0.96). We were also able to show trending of blood lactate with noninvasively determined hydrogen ion concentration, potentially allowing the noninvasive measurement of lactate threshold.

The NSBRI PI completed a document describing her experience in developing technology in collaboration with NASA. This document was distributed to NSBRI management.

Task Progress:

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- **Handgrip Exercise to Assess Fitness for EVA Tasks**

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