CLASSICS IN SPACE MEDICINE

Brannon EW, Rockwood CA, Potts P. *The influence of specific exercises in the prevention of debilitating musculoskeletal disorders; implication in physiological conditioning for prolonged weightlessness.* Aerosp Med 1963; 34: 900–6.

Judith C. Hayes, Deputy Chief, Human Adaptation and Countermeasures Division, NASA Johnson Space Center

This Classic paper was one of the first large bed rest studies of healthy, physically fit subjects to attempt to simulate the physiologic effects of prolonged "weightlessness" (now termed microgravity). Previous clinical studies of ill patients who were subjected to long periods of confinement and inactivity had clearly shown the development of bone demineralization, muscle atrophy, cardiovascular instability, and exercise intolerance. It was also well known that active physical therapy prevented these complications and effected a more rapid recovery. Inactivity experiments on healthy subjects had been carried out by previous researchers using complete immobilization in plaster casts and water submersion tests. In 1948, four subjects in plaster immobilization for 6 weeks showed decrease in muscle mass and strength, decrease in bone calcium, decrease in exercise tolerance, and decrease in metabolism with a slow, 6-week recovery phase (1). Closer to the time of this study, prolonged water immersion of normal test subjects for up to 2 weeks had resulted in orthostatic hypotension and mild loss of muscle strength (2). The authors of this Classic anticipated that long-term exposure to weightlessness during spaceflight might result in debilitating musculoskeletal effects. They pointed out that there was a profound lack of knowledge concerning the minimal threshold of exercise necessary to maintain muscle and bone integrity in a healthy individual, especially in a subgravity environment.

In this study, 30 healthy, young men who had just completed 6 weeks of USAF basic training were confined for 60 days of varying inactivity, with prescribed exercises and bed rest. Volunteers were divided into five groups and all were restricted to a single hospital ward and ate the same diet. There was an ambulatory control group, a group confined to complete bed rest with limited movement, and three groups confined to bed but allowed to exercise. Exercises were either calisthenic, isotonic, or isometric. Laboratory and physiological studies were performed weekly, including measurements of muscle strength and extremity circumference. Loss in muscle mass and strength were apparent in the bed-confined subjects after 2 weeks, especially in the lower extremities. During the recovery phase, subjects complained of unsteady gait, back and leg pain, exertional fatigue, and transient dizziness. Recovery required 30 days in subjects who had complete bed rest without exercise. The more exercise that was prescribed, the milder were the symptoms exhibited during recovery and the quicker was the recovery time. Only a small amount of exercise (less than 1 hour a day) was necessary to preserve muscle integrity. Isometric exercises appeared to work as well as classical isotonic exercises, which was important in that isometric exercises do not require equipment or gravity to perform and were more compatible with use during spaceflight. Although the authors acknowledged that bed rest was not completely analogous to the state of weightlessness in a spacecraft, they concluded that a cyclic regimen of isometric exercises could provide a practical conditioning program to prevent musculoskeletal deterioration during manned space ventures.

Background

There have been many bed rest studies since this initial study in 1963. NASA has used the 6° head-down bed rest model for decades to mimic some of the physiologic effects of spaceflight in humans. Most recently, standardization of the conditions and the dependent measures for NASA-sponsored bed rest studies have been implemented and conducted. The preliminary results of these studies have been published in a supplement of this journal (3, 4).

Exercise was first used as a countermeasure on Gemini 7, a 14-day orbital flight that used a simple bungee cord to give the two astronauts limited isotonic resistive exercise. In the Apollo Project, 20 out of 27 astronauts tested showed reduced postflight exercise tolerance, which returned to normal 36 hours after landing. The Skylab Project used a crude treadmill device, a cycle ergometer, and bungee cords as resistive exercise. As the first Skylab crew were found to be quite deconditioned following their 28-day flight, subsequent crews placed more emphasis on exercise. As a result, the third and final crew was found to be in much better condition after their 84-day flight than the first crew. It was noted that lower extremity strength was affected more than the upper extremities. The Skylab crewmembers all showed a significant decrement in response to submaximal exercise, but in-flight exercise reduced the time required for readaptation postflight.

Research continued in the Shuttle program and in the Soviet space program to develop countermeasure hardware and exercise prescriptions. These have included aerobic exercise, resistive exercise, diet, application of lower body negative pressure, and resistive "Penguin" suits. The exercise systems now on board the International Space Station (ISS) include a variety of modalities. The Russians provide a contingency non-motorized treadmill (currently stowed), a cycle ergometer, and a resistance exercise device. NASA provides two motorized treadmills for daily use, two resistance exercise devices (one is currently stowed), and a cycle ergometer. All astronauts and cosmonauts are allotted 2.5 hours per day for exercise, but this includes equipment deployment, reconfiguration, stowage, and clean-up, so that actual exercise time is approximately 1.5 hours. The prescriptions are customized for each crewmember by their trainers and exercise physiologists. The NASA exercise prescription generally includes daily aerobic exercise on either the cycle ergometer or the treadmill plus resistance exercises. There is no question that exercise is beneficial in slowing the muscle and cardiac deconditioning and improving postflight aerobic capacity, although there is little evidence to support a benefit in the prevention of bone loss.

Commentary

This paper was published during the Mercury flight program. Dr. Brannon was an USAF orthopedic surgeon and also served on the Primary Medical Support Team for Projects Mercury and Gemini as a flight surgeon and surgical consultant. He and his co-authors showed extraordinary foresight in anticipating the physiologic changes that would result from human space exploration. They were quite correct in that the deconditioning of muscle, bone, cardiovascular function, and aerobic capacity would become important as spaceflight duration increased beyond 2 weeks. Their judgment regarding the need to prevent deconditioning and to implement postflight recovery strategies were correct. They not only anticipated the use of exercise as a countermeasure, but were also concerned about identifying the optimum prescription for astronauts during future long-duration missions.

Many of the lessons learned from this landmark study led to standard conditions for current NASA-sponsored bed rest studies, such as the use of standardized diets, controlled environmental conditions, subject selection (e.g, matching for aerobic capacity and psychological evaluation), and the importance of social activities during bed rest and the tracking of post-bed rest recovery. Methods in this Classic study incorporated outcome measures that are still used in current experiments, including routine clinical laboratory evaluations (blood counts, chemistries, and urinalyses) and physiologic studies (bodyweight, heart rate, blood pressures, and basal metabolism). However, their de-

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DOI: 10.3357/ASEM.2687.2010

pendent variables were commensurate with the era and the available technology, while later studies have advanced to more objective measurements. Additionally, a characteristic of the times was that the investigators only enlisted young male recruits as test subjects so that limitations due to the youth, sex, and possibly race of their volunteers makes it difficult to generalize its results to current astronaut populations that are now decades older and include both sexes and many ethnicities. The study methods and logistics were well documented in this paper, outlining the challenges and limitations associated with this physiologic model for spaceflight. While this Classic offers a thorough record of the research methodology and carefully reports its qualitative data, the study lacks quantitative data and statistical analyses required for objective conclusions, and instead provides a set of 'impressions'.

Exercise countermeasures are extensively in use today on board the Space Shuttle and the ISS. Recent data on ISS astronauts show that current exercise regimens are beneficial in reducing much of the deconditioning effects associated with long-duration spaceflight. Regrettably though, optimal exercise prescriptions are yet to be solidified for current NASA astronauts on ISS and future exploration crews, as much of the same questions still exist regarding modalities, prescriptions, frequency, and intensity. This Classic study created a significant foundation for the decades of follow-on research that uses the bed rest model, albeit now using a 6° head-down position, to assess various countermeasures to the effects of simulated micro- or partial gravity as analogues to exploration missions in space.

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