

Exercise and Bone Health in Space

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There is a strong link between exercise and bone health both on Earth and in space. High impact loads on Earth are thought to stimulate bone. Studies of athletes who sustain high-impact loads, including figure skaters, tennis players, and runners, indicate a greater bone mineral density when compared with controls (Chilibeck et al., 1995). In space, since upper extremity bone mass is largely preserved (LeBlanc, et al., 1996), it is thought that disuse of the lower extremity may be the principal mechanism of bone loss.

The human skeleton has evolved in an environment where the force of Earth's gravity has been a continual presence. It is, therefore, not surprising that removal of gravity during long-duration space flight results in a loss of homeostasis in the skeleton which, in MIR and ISS Expeditions 2-6, adapted to the new environment by losing bone mineral density (Lang et al., 2004) at a rate that was almost 10 times greater than that in a postmenopausal woman (Iki et al., 1996; Sirola et al., 2003). This adaptation to microgravity renders the skeleton "at risk" for fracture, increases the risk of renal stones (Whitson et al., 1999), and poses potential long-term health risks for astronauts on their return to Earth with reduced bone mass.

Exercise is presently the primary countermeasure to bone demineralization during space flight. However, it is clear that the osteogenic stimulus from exercise prescriptions so far has been inadequate to maintain bone mass, probably due to insufficient load or duration. It is also possible that an equivalent daily load to that experienced on Earth cannot be fully replaced in brief exercise periods.

We have conducted an experiment on the International Space Station (ISS) designed to measure loads on the feet over an entire day in the same subject during daily life on the ground and on the ISS. Daily load stimulus (DLS), a mathematical model used to relate changes in bone mineral density to daily loading histories, was calculated using in-shoe force profile data. These data suggest that loading in space over an entire work day provided only approximately half the stimulus to bone experienced during a typical work day on Earth.

A NASA Bedrest Study is being performed at the Cleveland Clinic Foundation (CCF) to further test the DLS theory. Subjects will be randomized to control or exercise groups and confined to strict, supervised 6-degree head-down bedrest for 12 weeks. During this time, the exercise group will undergo individualized daily exercise programs in the Zero Gravity Locomotion Simulator (ZLS) at CCF designed to replace their daily mechanical load stimulus experienced during free living. The proposed experiment should provide a categorical answer to the question of whether intermittent load replacement can adequately protect the musculoskeletal system against hypokinetic osteopenia and muscle atrophy and may demonstrate the efficacy of individualized exercise countermeasure planning.

In this talk, we will examine the evidence for loss of bone mass during long-duration space flight, discuss the mechanisms for such loss, review countermeasures that have been attempted to date, and examine the potential of pharmaceutical countermeasures in the future (Cavanagh et al., 2005). The implications of recent findings regarding the genetic determinants of bone mass will also be discussed.

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