

Modeling the Effects of Microgravity on Proximal Tibia Bone Stiffness in Mice

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ABSTRACT

Studies and experience in spaceflight has shown that the absence of gravity in the skeleton will cause severe declines in total bone mass, often greatly compromising load bearing joints and members. Astronauts manning long duration spaceflights experience substantial bone loss, which include microstructural changes in cortical and trabecular bone. These microstructural changes decrease the overall stiffness of the bone, often leading to increased likelihood of fracture with increased age. However, exactly how much bone loss is incurred is not known. The objective of this study is to investigate how spaceflight affects the bone strength in mice through computational finite element modeling. Three groups of mice were used in this study each with n=15: Mice flown on Space Shuttle Mission STS-135, a baseline, and control group. The tibia was excised from each mouse and, in the case of the Spaceflight group, the excision was performed immediately upon landing. The bones were scanned in a micro CT scanner at 10 μ m isometric resolution. To perform analysis on these models, the 3D image data was exported into a finite element mesh. After which uniaxial compression was simulated on a 1.0 mm thick section of the proximal tibia to determine the effective stiffness of the bone structure at this location. The bone was compressed to 5% of total height and the resultant force output was measured, which provides the effective stiffness of the bone specimen. The results showed a statistically significant decrease in bone strength between the mice aboard the spacecraft and the other two groups. The results from the model showed that the overall stiffness in the bones of the spaceflight group was 39% less than that of the ground control group ($P < 0.001$), and the flight group's were 27% less stiff than the baseline group ($P < 0.001$). This study provides data to serve as a reference point of the expected degradation of bone strength in mice. Future work could extrapolate on this mouse model and translate this loss of bone strength to humans. The model in this study only considered the elastic behavior for bone. Future work could incorporate a plastic material model to investigate damage to the bone for fracture risk assessment, which can be applied to bone loss from spaceflight as well osteoporosis in the aging population.