RISK ASSESSMENT OF BONE FRACTURE DURING SPACE EXPLORATION MISSIONS TO THE MOON AND MARS

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Bone fracture risk assessment is one component of NASA's Integrated Medical Model, which is a tool for quantifying the probability and consequences of medical risks during spaceflight. The possibility of a traumatic bone fracture in space is a concern due to the observed 1-2% per month localized decrease in astronaut bone mineral density (BMD) during spaceflight and because of the physical demands that will be placed on astronauts as they construct a lunar or Martian base. This leads to the risk statement: "*Given that astronauts could experience significant skeletal loading during planetary activities, particularly in areas where bone is compromised due to BMD reduction from low-g exposure, there is the possibility of bone fracture leading to astronaut impairment or significant mission impact.*" Despite the common terrestrial understanding of the increased fracture risk with bone loss, very little directly attributable data is available to support quantified fracture probabilities during a space mission that is suitable for use in decision making or for defining initiating and pivotal event functions in probabilistic risk assessment (PRA) simulations. As is the case with many clinically significant medical events in space, the problem has many contributing factors that are confounded by space travel, especially the physiological effects of long duration exposure to microgravity. In the case of bone fracture, the process is further confounded by the fact that an external event is necessary to initiate the occurrence. In our efforts to address the likelihood and impact of medical events during exploration missions for use in PRA analysis, we developed a methodology for determining probability estimates by integrating the effects of the multitude of contributing physiological and external factors through a simulation based approach, similar to a simulation PRA analysis. The first application of this methodology was in the area of bone fracture.

In the case of predictions of bone fracture, the likelihood of injury on an exploration mission is assessed with a mathematical model developed to combine known parameters of bone loss in space (pre and post flight BMD levels), estimates of terrestrial bone strength at the estimated mission BMD levels (from *ex vivo* tests) and skeletal loading from planetary surface activities (from biomechanical loading models). The model calculates a bone Fracture Risk Index (FRI) by comparing the skeletal loading during an activity to the ultimate strength of the bone (more detail on the complexity of the FRI calculation is given in *Calculation Of Fracture Risk Index To Assess The Risk Of Bone Fracture During Space Exploration Missions* by Lewandowski et al. Submitted to the 2008 Space Systems Engineering and Risk Management Symposium). The FRI is transformed into a probability of fracture using a simplified fault tree approach that combines the likelihood of the loading condition with the estimated probability of a fracture given the calculated FRI. To account for the uncertainty of the model a distribution of values from the contributing literature was used to describe the parameters and a Monte Carlo simulation was performed to generate a probability density functions for the probability of fracture.

Our preliminary results indicate that there is a small, but non-negligible risk of bone fracture during a Mars mission. However, the model shows a wide uncertainty in the fracture probability and indicates several areas where additional information can improve the model predictions. Since the consequences of a fracture to the mission and crew are severe, the thrust of ongoing work will be to “buy down” this uncertainty by improving the data and simulations and identifying approaches to mitigate the risk of fracture. In the near future, we will be implementing our simulation approach to medical events in the areas of renal stone formation, muscular performance and behavioral health and performance.