The Extravehicular Suit Impact Load Attenuation Study for Use in Astronaut Bone Fracture Prediction

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INTRODUCTION

The NASA Integrated Medical Model (IMM) assesses the risk, including likelihood and impact of occurrence, of all credible in-flight medical conditions. Fracture of the proximal femur is a traumatic injury that would likely result in loss of mission if it were to happen during spaceflight. The low gravity exposure causes decreases in bone mineral density which heightens the concern. Researchers at the NASA Glenn Research Center have quantified bone fracture probability during spaceflight with a probabilistic model. It was assumed that a pressurized extravehicular activity (EVA) suit would attenuate load during a fall, but no supporting data was available. The suit impact load attenuation study was performed to collect analogous data.

METHODS

A pressurized EVA suit analog test bed was used to study how the offset, defined as the gap between the suit and the astronaut's body, impact load magnitude and suit operating pressure affects the attenuation of impact load. The attenuation data was incorporated into the probabilistic model of bone fracture as a function of these factors, replacing a load attenuation value based on commercial hip protectors.

RESULTS

Load attenuation was more dependent on offset than on pressurization or load magnitude, especially at small offsets. Load attenuation factors for offsets between 0.1 – 1.5 cm were 0.69 ± 0.15, 0.49 ± 0.22 and 0.35 ± 0.18 for mean impact forces of 4827, 6400 and 8467 N, respectively. Load attenuation factors for offsets of 2.8 – 5.3 cm were 0.93 ± 0.2, 0.94 ± 0.1 and 0.84 ± 0.5, for the same mean impact forces. Reductions were observed in the 95th percentile confidence interval of the bone fracture probability predictions.

CONCLUSIONS

The reduction in uncertainty and improved confidence in bone fracture predictions increased the fidelity and credibility of the fracture risk model and its benefit to mission design and operational decisions.

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BACKGROUND

NASA's Integrated Medical Model

- A probabilistic, simulation-based tool used to predict the rate of occurrence of in-flight medical events
- Used to help determine the relative risk of medical events that could occur in space
- Used to help optimize mitigation tools, such as the in flight medical kit
- Probabilistic risk assessment methods are utilized in combination with the best available spaceflight data , evidence and relevant terrestrial databases

Bone Fracture Risk During Space Flight

- Proximal femur fracture is a traumatic injury, likely resulting in loss of mission if it were to occur during spaceflight
- Low gravity exposure causes decreases in bone mineral density, which heightens the concern of fracture
- The Bone Fracture Risk Module (BFxRM) is a probabilistic model used to quantify bone fracture probability during spaceflight
- It was assumed that a pressurized extravehicular activity (EVA) suit would attenuate load during a fall, but no supporting data was available
- The Suit Impact Load Attenuation Study was performed to collect analogous data

METHODS

The Suit Impact Load Attenuation Study

- A pressurized EVA suit analog test bed was used
- The affects of offset (the gap between the suit and the astronaut's body), impact load magnitude and suit operating pressure on impact load were studied
- The equation used to calculate the experimental attenuation (A_{Exp}) of the EVA suit analog was: $A_{Exp} = \frac{(F_o - F)}{F_o}$

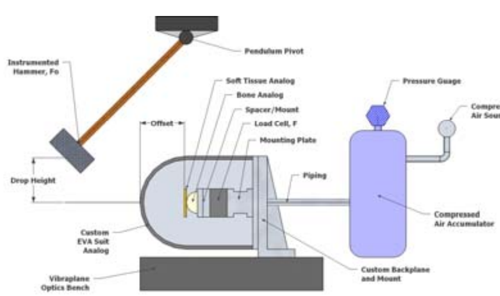
where, F_o is the average measured reference impact force and F is the average measured force at the analog hip, after attenuation due to the suit

- The experimental attenuation factor and offsets were fitted to the following equation:

$$A_{Fit} = aOS^b$$

where, A_{Fit} is the fitted attenuation, OS is the offset and a and b are regression constants

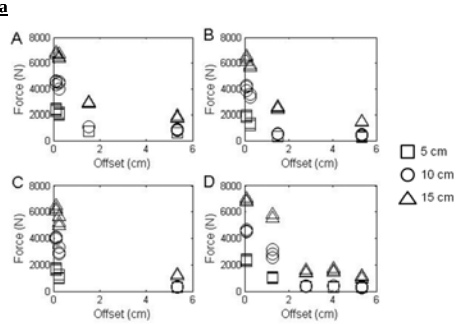
- A comparison was made between BFxRM predictions made with the new attenuation factor and the old attenuation factor, which was based on commercial hip protectors



The pressurized EVA suit analog test bed

RESULTS

Impact Force Data

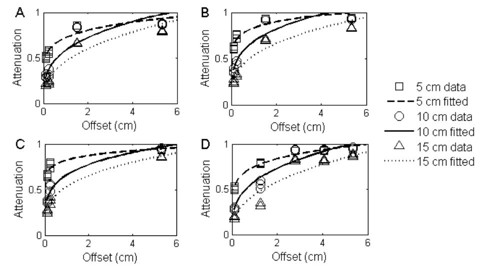


Experimental suit impact force data vs. offset . Three different drop heights (5cm, 10 cm and 15 cm) and four different EVA suit analog pressurizations were used: A. 27 kPa; B. 29 kPa; C. 32 kPa; D. 33 kPa. Three trials were performed at each test condition.

RESULTS (Con't)

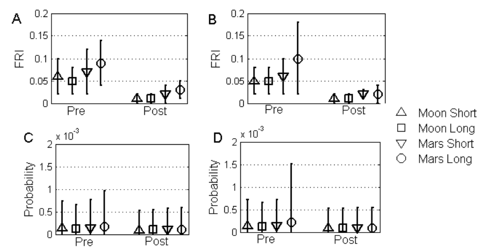
Load Attenuation Was Most Dependent On Offset

- Load attenuation factors for offsets between 0.1 – 1.5 cm were 0.69 ± 0.15, 0.49 ± 0.22 and 0.35 ± 0.18 for mean impact forces of 4827, 6400 and 8467 N, respectively
- Load attenuation factors for offsets of 2.8 – 5.3 cm were 0.93 ± 0.2, 0.94 ± 0.1 and 0.84 ± 0.5, for the same mean impact forces



Attenuation factor vs. offset for three different drop heights and four different EVA suit analog pressurizations: A. 27 kPa; B. 29 kPa; C. 32 kPa; D. 33 kPa. Three trials were performed at each test condition. A curve was fit through each set of attenuation values

- Reductions were observed in the mean value and the 95th percentile confidence interval of the bone fracture probability predictions



Comparison of BFxRM prediction results for Fracture Risk Index (FRI) and fracture probability between the use of hip protector data and the experimental data for characterization of EVA suit attenuation. Predictions for four different mission scenarios were performed: moon short, moon long, Mars short and Mars long for both male and female astronauts. A. Male FRI Results; B. Female FRI Results; C. Male Probability Results; D. Female Probability Results.

DISCUSSION

A Higher Fidelity Model Was Created

- Attenuation was more dependent on offset than pressurization or loading, especially at small offset values
- This study reduced the sensitivity of the model to the suit attenuation factor
- The fidelity of the BFxRM was increased by making the attenuation factor a function of pressure, impact load and offset.
- The findings of this study are beneficial to suit designers because it elucidates how fracture risk is dependent on the conformity of the suit.
- The reduced uncertainty is also beneficial to mission planners as it provides more assurance that the true fracture risk is understood, is lower than previous predictions indicated, and can more readily inform decisions that utilize complex comparison analyses of these predictions with other medical risks.

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