Glenn Research Center
Human Research Program

Probabilistic Risk Assessment for Astronaut Post Flight Bone Fracture

Beth Lewandowski, PhD, NASA GRC

Jerry Myers, PhD, NASA GRC

Angelo Licata, MD PhD, Cleveland Clinic

Overview

- Why the Bone Fracture Risk Module (BFxRM) was developed
- The probabilistic methods used for making fracture likelihood estimates
- Application of the BFxRM in estimating mission fracture risk
- BFxRM estimates of post-flight fracture risk
- Areas for future improvement and application of the BFxRM

Why the Bone Fracture Risk Module (BFxRM) was developed

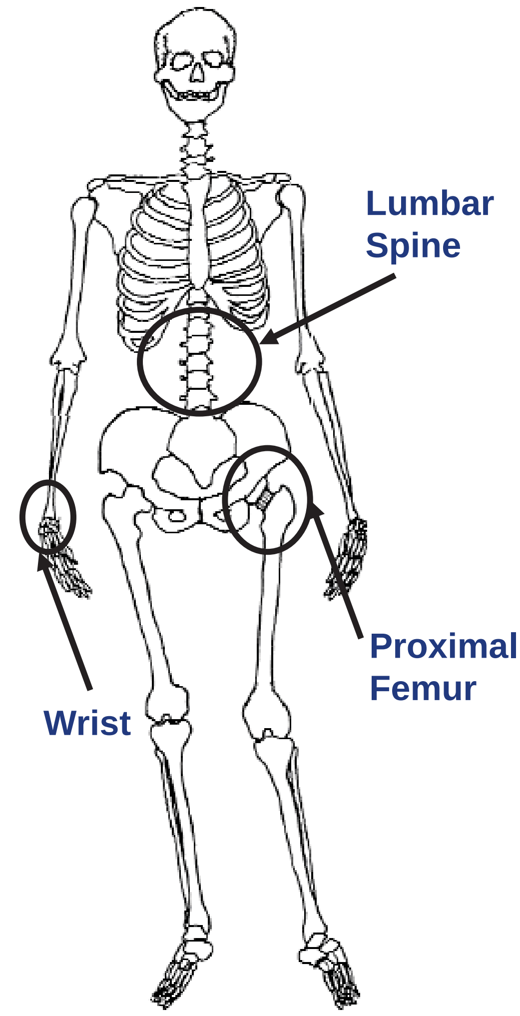
- Historically, fracture probability calculations have been used for preventative treatment planning in specific clinical populations

- The DXA/T-score system has been used
  - To assess risk of fragility fractures
  - Typically applied to an elderly, female, postmenopausal, Caucasian population with a high prevalence of osteoporosis

- This reference population is not analogous to the astronaut corps
  - Those at high risk have T-scores ≤ -2.5 (2.5 standard deviations less than the population mean)
  - Astronauts are young, healthy, physically fit, work in a unique environment and are engaged in unique activities

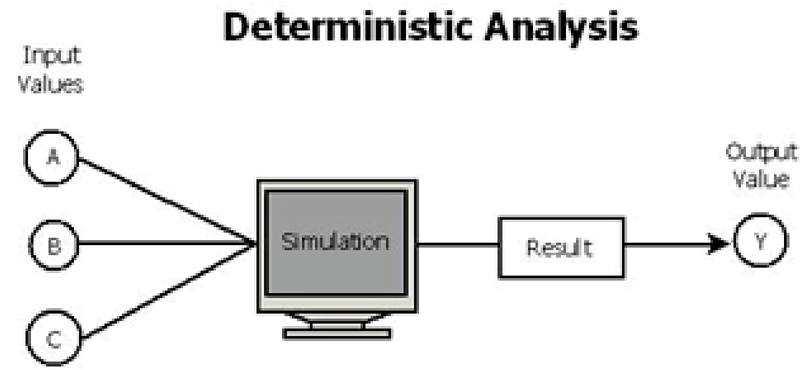
The BFxRM was developed for assessing fracture likelihood during missions

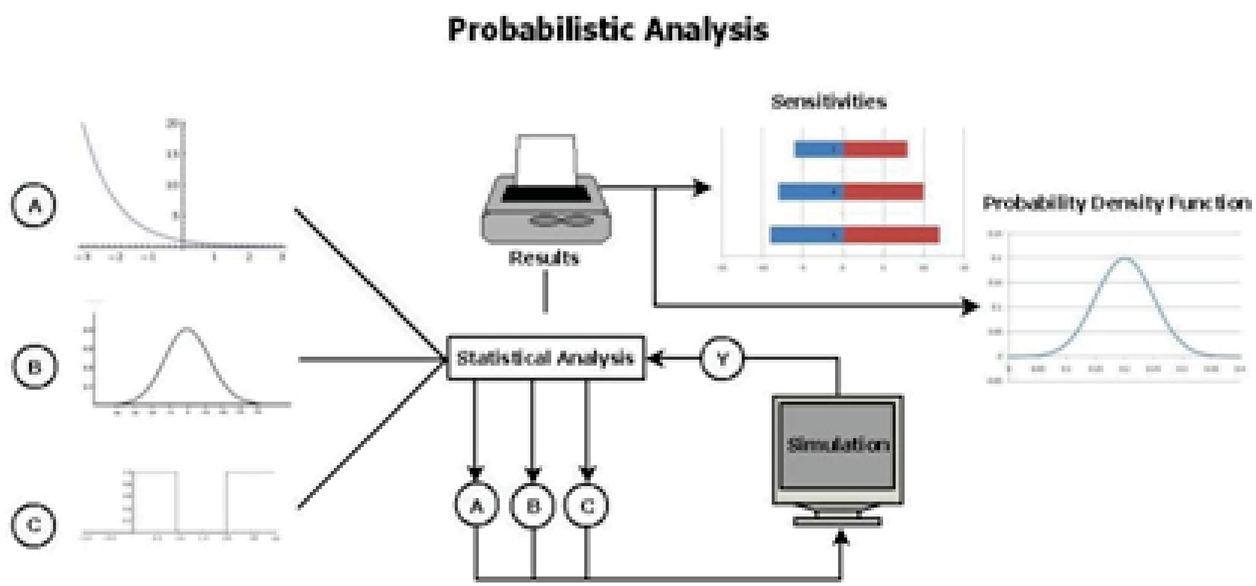
- Skeletal fracture is a concern for astronauts due to:
  - The loss of bone mineral density experienced
  - The unique loading states experienced
- The calculation of fracture likelihood was desired for:
  - In-flight activities (on space station and in new crew capsules)
  - During planetary activities (on Earth, Moon and Mars)
- Prediction capabilities were limited due to the lack of historical injuries
- The goals of the BFxRM were to:
  - Capture the state of knowledge and uncertainty of the likelihood of fracture
  - Incorporate mission related factors, environmental influences, and the best available clinical and biomedical knowledge in a probabilistic risk analysis



Probabilistic risk assessment (PRA) simulation models

- Include physical models, physiological data and probabilistic simulations
- Acts as integrator for the interacting contributing conditions
- Integration obtained with Monte Carlo simulations

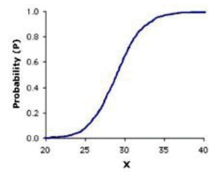


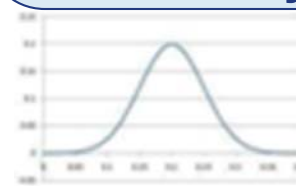


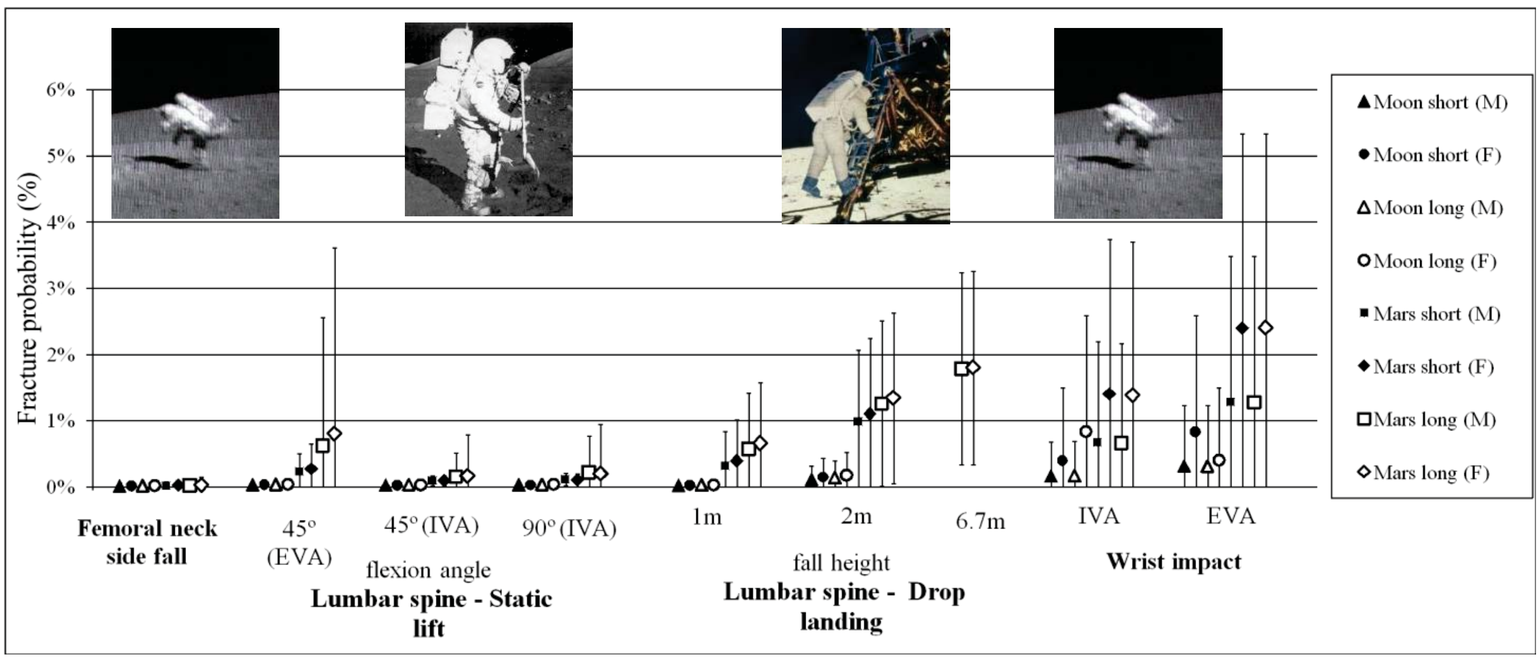
The BFxRM for mission likelihood estimates

Monte Carlo Simulation

Probability and magnitude of loading event → **Estimate relative skeletal strength** → **Est. fx probability by load to strength ratio** → **Most likely probability of fracture for event + uncertainty**







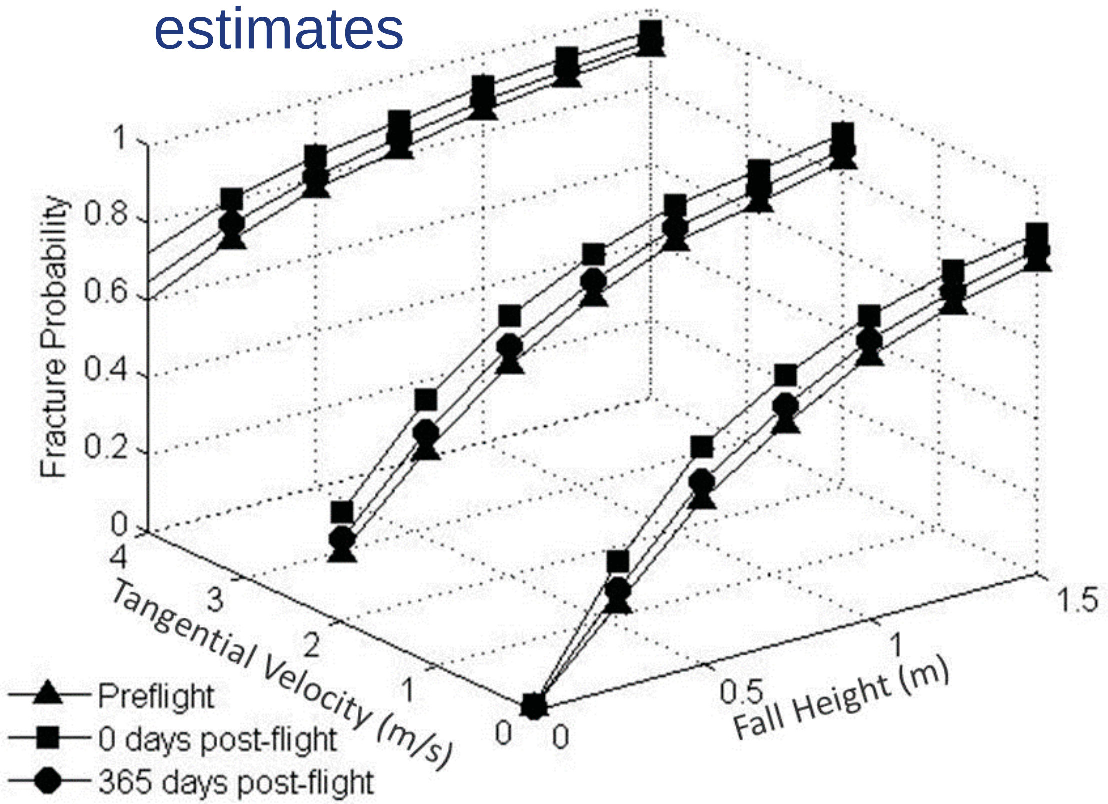
Nelson et al., ***Development and Validation of a Predictive Bone Fracture Risk Model for Astronauts***, Annals of Biomedical Engineering, 2009, Vol. 37, Number 11, 2337-2359.

Post-flight fracture risk

- Quantification of the increased likelihood of fracture during post-flight activities
  - Specific loading scenarios were modeled:
    - Elevated, unprotected falls
    - Impacts that included a translational velocity
- Informed injury criteria definition
  - Injury loading threshold for off-nominal Orion landings
  - Developed a deconditioning factor to help guide risk decisions

Post-flight fracture risk – Unprotected lateral fall

- Loading conditions:
  - Lateral falls from 0-1.5 m heights
  - Translational velocity 0-4 m/s
  - No protective action or equipment
- BMD loss:
  - LeBlanc BMD loss rate
  - Deconditioning during a 6 month flight
- BMD recovery:
  - Sibonga recovery rate
  - Estimates at 0 and 365 days post-flight
- Mean fracture probability:
  - 12% greater than preflight on day 0
  - 5% greater than preflight on day 365
- Parameter uncertainty drives the large variance in fracture probability estimates



Post-flight fracture risk – Off-nominal landing

- Estimated deconditioned vs. preflight bone strength

- Loading conditions:
  - Loading at the femoral neck
  - Similar to lateral fall loading
  - No protective equipment considered
  - Landing surface is land rather than water

- BMD loss:
  - LeBlanc BMD loss rate
  - Deconditioning during a 6 month flight
  - No recovery time

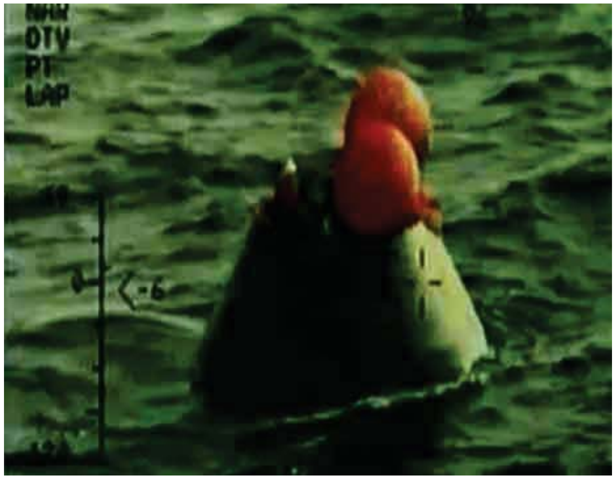
$$FRI_{Pre} = \beta FRI_{Post}$$

$$\beta = \frac{BS_{Post}}{BS_{Pre}}$$

$$\Phi = \beta_M - 2\sigma_\beta$$

$$\Phi \sim 0.80$$

- The deconditioning factor was defined as the 5th percentile value of β



BFxRM results summary

- The BFxRM provides fracture risk estimates specifically for the astronaut population and for the activities they perform
  - Spaceflight mission scenarios (in-flight activities and EVAs)
  - Return and post-flight scenarios (off-nominal landings, post-flight activities)

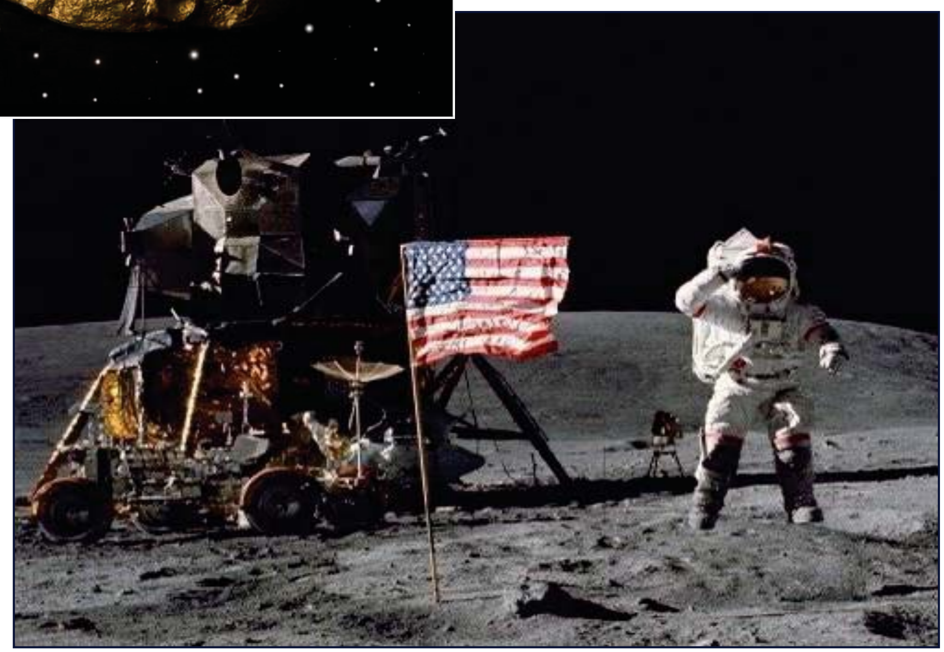
- Astronaut fracture resistance after 6 months in space decreases to
  - A mean value of 12% less than pre-flight values at return, with a 5^{th} percentile of 20% less
  - A mean value of 5% less than pre-flight values at one year after return for active lifestyle, off-nominal loading conditions

- The uncertainty associated with the fracture risk estimates can be significant

- The source of the uncertainty is due to significant uncertainty in the sensitive parameters
  - Using the change in BMD as the only factor that contributes to changes in bone strength during spaceflight
  - Using simplifying assumptions within the biomechanical loading calculations

Areas for future improvement and application of the BFxRM

- Improved representation of bone and fracture conditions
  - Use biomechanical information about real fracture events to improve the function that translates the load to ultimate strength ratio to fracture probability
  - Integrate FEM and other “bone quality parameters” to increase the fidelity of the bone strength estimate
- Perform additional validation and credibility testing
- Address the impacts of other space flight adaptations and countermeasure use
  - Considering micro-architecture in addition to BMD to predict ultimate strength
  - Bisphosphonates, diet and (ARED, AEC) exercise
- Influence mission planning and operational environment
  - Spacecraft, spacesuit and habitat designs
  - Operational processes and specific training



QUESTIONS?