Computational Modeling of Space Physiology for Informing Spaceflight Countermeasure Design and Predictions of Efficacy

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Spaceflight Countermeasures

- Exercise
- Lower body negative pressure/blood flow occlusion
- Artificial gravity
Computational Models Used to Inform Spaceflight Countermeasure Design and Efficacy Prediction

Musculoskeletal system & Biomechanical modeling
Bone and muscle

Lumped-parameter whole body model
Vasculature, cerebral spinal fluid and lymphatic fluid, heart, eye, kidney

Central nervous system
Vestibular organs
Biomechanical Modeling

• Estimation of kinematics, joint torques, muscle forces and joint reaction forces

• Data includes: motion data, ground reaction forces, device loads and subject anthropometrics
Applications of Biomechanical Modeling

• Comparison of new exploration exercise devices to ground-based free weight exercises

• Determination of exercise operational volume

• Interface load estimation
Musculoskeletal Modeling

- Muscle atrophy model
- Models for estimating changes in bone mineral density and bone strength
- Prediction of bone fracture probability

Muscle Atrophy Model
PI Silvia Blemker, University of Virginia

- Dynamic simulation of exercises
- 3D simulation of muscle tissue contraction
- Agent-based simulation of muscle adaptation


Bone fracture risk model

Applied Load

Bone Strength

Fracture Risk Index

Fracture Probability

Biomechanical model

Joint forces

Strain within the bone

Daily load stimulus

Changes in Bone Mineral Density

Percent decrease in muscle size for spaceflight, bed rest, immobilization and unilateral limb suspension
Applications of Musculoskeletal Modeling

Predictions of the likelihood of bone fracture

Deconditioning factor for vehicle load limit design

Comparison of pre- and post-flight mean bone strengths associated with ISS missions to applied loads

Estimation of countermeasure efficacy

Investigation to determine if spaceflight increased the probability of the fracture
Cardiovascular and Ocular Modeling

- A human body model of cardiovascular, cerebral spinal, interstitial and lymphatic fluids that provides mean arterial pressure (MAP) and intracranial pressure (ICP) in response to gravity-driven fluid shifts
- A lumped eye model that provides intraocular pressure (IOP) and globe and blood volume estimates
- A finite element model of the optic nerve head that includes tissue properties so that tissue strains can be estimated when subjected to different MAP, ICP and IOP
Applications of Cardiovascular and Ocular Modeling

- **Support Visual Impairment and Intracranial Pressure (VIIP) syndrome research**
  - Provide insight on how intraocular pressure and aqueous humor volume change during acute gravitational changes
  - Determine physiological factors that most affect the IOP changes
  - Explore the hypothesis that the pathology of VIIP is due to altered biomechanical loads on ocular tissues, which causes remodeling of the ocular tissues
  - Determine factors with the largest influence on strain
  - Determine characteristics describing the population that would experience peak strains in the optic nerve during microgravity

- **Inform countermeasure design**
  - Incorporate countermeasures simulation capabilities into compartment models to evaluate the effects of microgravity and countermeasures on CSF and blood flows and pressures
Conclusions

- Computational modeling can be used to support spaceflight research and countermeasure design
  - Develop and perform simulations to test hypotheses
  - Determine key factors of the system to aid experimental design

- Computational modeling can be used to perform simulations that reduce the number of required experimental tests
  - Provide predictions and answers to ‘What If?’ questions
  - Perform simulated experimental trials
Thank You!!

Questions?