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

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88th Annual Scientific Meeting
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I have no financial relationships to disclose.

I will not discuss off-label use and/or investigational use in my presentation.
Spaceflight Countermeasures

- Exercise
- Lower body negative pressure/blood flow occlusion
- Artificial gravity
Computation 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

Applied Load
Bone
fracture risk
model

Bone Strength

Bone fracture risk
model

Fracture Risk Index
Fracture Probability

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


Percent decrease in muscle size for spaceflight, bed rest, immobilization and unilateral limb suspension

Joint forces
Strain within the bone

Daily load stimulus

Changes in Bone Mineral Density

Biomechanical model

Applications of Musculoskeletal Modeling

Predictions of the likelihood of bone fracture

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

Deconditioning factor for vehicle load limit design

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.

Modeling capabilities across multiple spatial scales.

PI C. Ross Ethier
Georgia Institute of Technology
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

Latin Hypercube Sampling (LHS)

Changes in Bone Mineral Density

Mean Arterial Pressure (mmHg)
Intraocular Pressure (mmHg)
Upright  Supine  Elevated

ONH Material Properties
(SC, ppSC, LC, Pia, Dura, ON, Prelaminar, RV and Poisson’s)
Thank You!!

Questions?