THE CLEVELAND CLINIC FOUNDATION

FOOT REACTION FORCES DURING SIMULATED ISS EXERCISE COUNTERMEASURES

P.R. Cavanagh,[1,2,3,4] B. L. Davis,[1,2,3,4] A.J. Rice,[1,2] K.O. Genc,[1,2] M.L. Just,[5] C.M. Grodsinsky,[5] G.P. Perusek[6]

[1]The Cleveland Clinic Foundation Center for Space Medicine, [2]Departments of Biomedical Engineering and [3]Orthopaedic Surgery and the [4]Orthopaedic Research Center

[5]Zin Technologies, [6]NASA Glenn Research Center

1. Background

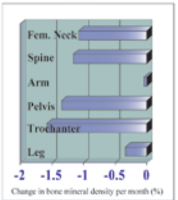
Bone Loss in Space

Skeleton unloaded by microgravity

↓

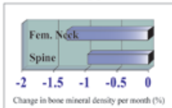
1-2% loss of bone mineral density in lower extremity each month.

MIR



LeBlanc et al., 1996

ISS



Lang et al., 2004

Despite improved exercise countermeasure devices, bone loss is **still** occurring on the ISS.

Mechanisms

Uncoupling of Formation and Resorption

180-day MIR flight
n = 1 in-flight, n = 2 pre/post-flight

Resorption markers: ↑
- CTX (procollagen C-telopeptide).......... 78%
- Deoxypyridinoline (free)..................... 58%

Formation markers: ↓
- Bone alkaline phosphatase................. 27%
- Osteocalcin.. 38%
- Type I procollagen peptide................. 28%

- Currently, exercise is the only countermeasure to negative physiological effects of space flight including bone loss.
- Microgravity environment during exercise has not been fully characterized.
- Exercise "dose" currently delivered to crew members (load, F; and loading rate, dF/dt) is unknown.

2. Significance

NASA Critical Path Roadmap

Risks associated with Bone Loss	Enabling Questions
Acceleration of age related osteoporosis	What are the **specifics of the optimal exercise regimen** (mode, duration, intensity and frequency) to be followed so as to **minimize decreases in bone mass**? (EQ 1-4)
Fracture and impaired fracture healing	Is **impact loading** an essential element and, if so, how can it be produced in hypogravity?
Renal stone formation	What **hardware and/or technologies** are currently available, or need to be developed for an ISS, lunar, and Mars mission in order to **simulate** the type of musculoskeletal **loading experienced here on Earth**? (EQ 13-x)

3. Objectives

- Improve validity of human supine suspension microgravity simulation. Develop hardware/software to characterize F, dF/dt, vibratory response and transmission of load to the human body during exercise on grounded, compliant, and floating surfaces.
- Characterize lower-extremity loading during simulated 0-g exercise on treadmill, cycle ergometer, and resistance exercise devices throughout the range of Subject Load Device (SLD) and harness settings.
- Propose an exercise regimen on these devices for effective maintenance of bone and muscle mass.

Hypothesis

→ Musculoskeletal loading will be significantly affected by realistic mechanical interfaces for exercise devices.

→ Key loading parameters affecting the musculoskeletal system will be significantly different between the three modes of exercise.

→ a) SLD settings greater than the present ISS settings are critical to maintain musculoskeletal integrity.
b) Effective exercise prescriptions can be devised based on comparisons of daily 1-g loading and those measured during simulated 0-g exercise.

4. Current Countermeasures

Treadmill Vibration Isolation System (TVIS)

- A "floating" surface developed by NASA for ISS
- Simulates running in 1g by tethering crewmembers to its vibration isolated running surface by:
  - -SLD or
  - -Various bungee cables

Simulated 1g Exercise = Mechanical "dose" needed to help maintain bone density.

iRED (Interim Resistive Exercise Device)

Canisters or "flex packs" provide resistance for the exercise

CEVIS (Cycle Ergometer Vibration Isolation System)

Provides aerobic and cardiovascular conditioning through cycling activities

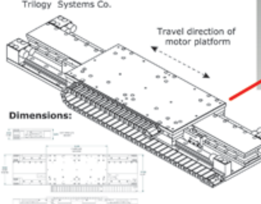
5. Hardware

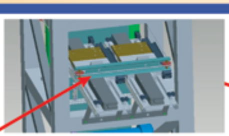
Enhanced Zero Gravity Locomotion Simulator (eZLS) under development at NASA GRC:

- TVIS, CEVIS, iRED exercise modalities and crew SLDs may be evaluated for biomechanical loading in the eZLS, a ground-based simulator, which simulates on-orbit exercise.
- Exercise device (treadmill shown) with integrated force plate and SLD assembly ride on frictionless air-bearing table, 1 DOF or 3 DOF motion possible.
- Variably compliant isolators simulate different ISS exercise countermeasure device dynamics.
- Flexible configuration to accommodate future exercise countermeasure device concepts.

New Linear SLD Motors

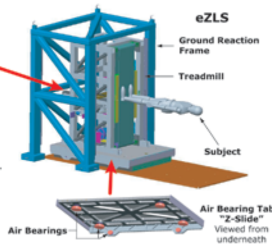
Trilogy Systems Co.



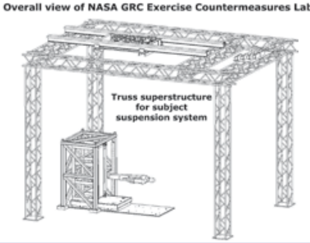


- Two brushless linear motors controlled by servo amplifier and force transducer feedback.
- Pulls subject toward running surface with a constant force.
- Force can be scaled to Earth, Lunar or Mars gravity.

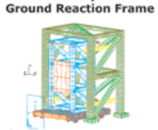
eZLS



Overall view of NASA GRC Exercise Countermeasures Lab



FEM analysis of Ground Reaction Frame



Requirements:
- -Frequency = 70 Hz Minimum in direction of motion of the Z-slide or ~ 3X Bandwidth of interest

Finite Element Model Features:
- -Plate and Brick Elements
- -16 Constraints

Results:

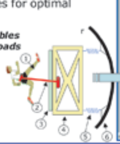
Mode 1	52 Hz (side to side)
Mode 2	**70 Hz (Z-axis)**
Mode 3	104 Hz

6. Modeling

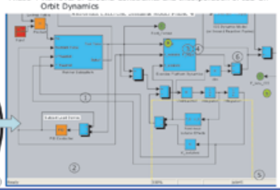
Observation: Numerous on-orbit and ground based studies show that bone loss is greatly dependent on peak reaction forces and other dynamic load conditions.

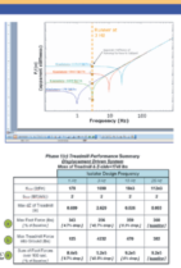
Tasks at Hand: 1) Characterize these reaction forces for various G load conditions. **2)** Predict and control these reaction forces for optimal benefit to astronaut.

The interplay between these variables will directly affect reaction force loads on subject's bones:
1. Biomechanics;
2. Subject Load Device (SLD);
3. Treadmill Dynamics;
4. Rack Dynamics;
5. Isolation Elements;
6. ISS Structural Dynamics.



Modeling and Validation is Conducted in 4 Phases:
- Phase 1-Rigid Body Dynamics and Isolator Development
- Phase 2-Incorporation of Passive Restraint Device and Higher-order Platform Dynamics
- Phase 3-Incorporation of Active Subject Load Device and Bio-Mechanically Accurate Runner Dynamics
- Phase 4-Removal of Ground Constraints and Incorporation of ISS On-Orbit Dynamics





7. Summary

- The microgravity exercise environment has not been adequately studied or modeled.
- The presented multi-disciplinary approach promises to address the relevant issues at many important levels:
  - The human dose response level to mechanical stimuli
  - The effects of exercise on the microgravity environment from a directly measured and mathematical point of view.
  - The effects of interface compliance on the efficacy of exercise
- The SLD is currently being tested at the biomechanics laboratory at the Cleveland Clinic.
- The model is currently being developed by engineers at ZIN Technologies
- The eZLS is currently under construction at the Glenn Research Center in Cleveland OH.

8. References

Lang et al., J Bone Miner Res, 19(6) (2004)

LeBlanc et al., J Bone Miner Res, 11:S323 (1996)

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Contact:

E-mail: Peter R. Cavanagh: cavanap@ccf.org
Web: www.lerner.ccf.org/bme/