# Bone Fracture Research Plan

ASSESSING THE PROBABILITY OF OVERLOADING BONES BY HHC FOR EXMC RISK MANAGEMENT

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# Fracture Research

Exploration Medical Capabilities [ExMC]

Human Health Countermeasures [HHC]

"Fracture" Gaps

"Osteoporosis" Gaps

**Risk for Fracture due to Spaceflight-induced Changes to Bone**

*Understanding fracture probability during spaceflight operations [OPS]*

Medical capabilities & in-flight countermeasures

- to reduce probability,
- to treat,
- to enhance healing,
- to rehabilitate.

*Understanding how spaceflight changes bone.*

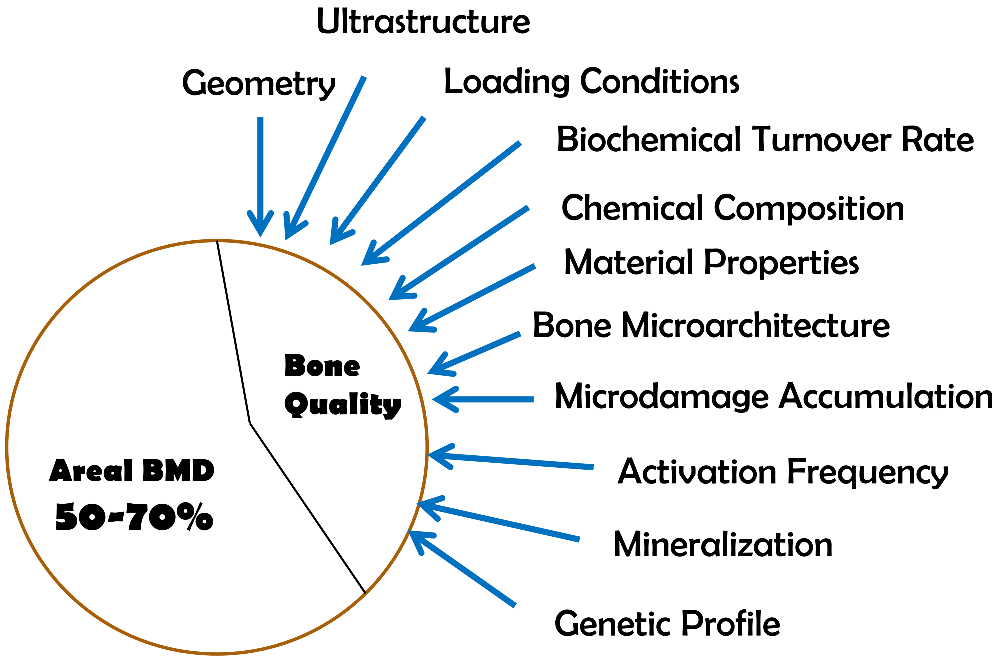
- Technology Development to expand bone measurements
- "Expanded" Data input to model biomechanical competence
- Level 4 Evidence to establish clinical utility

# Clinical Medicine: "Bone Quality: What is it and Can we measure it?"

Bethesda, MD, **May 2005**

"Osteoporosis is a skeletal disorder characterized by compromised bone strength predisposing to an increased risk of fracture. **Bone strength reflects the integration of two main features: bone density and bone quality.**"

**JAMA 2001**




## 2010 Bone Summit (Research & Clinical Advisory Panel – RCAP)

2010 Charge: What Bone Quality measurement is essential for Risk Surveillance in astronauts?

Orwoll et al, Journal of Bone & Mineral Research 28(6):1243-1255, 2013

# Post-Bone Summit : Fracture Research Plan to increase understanding of spaceflight changes

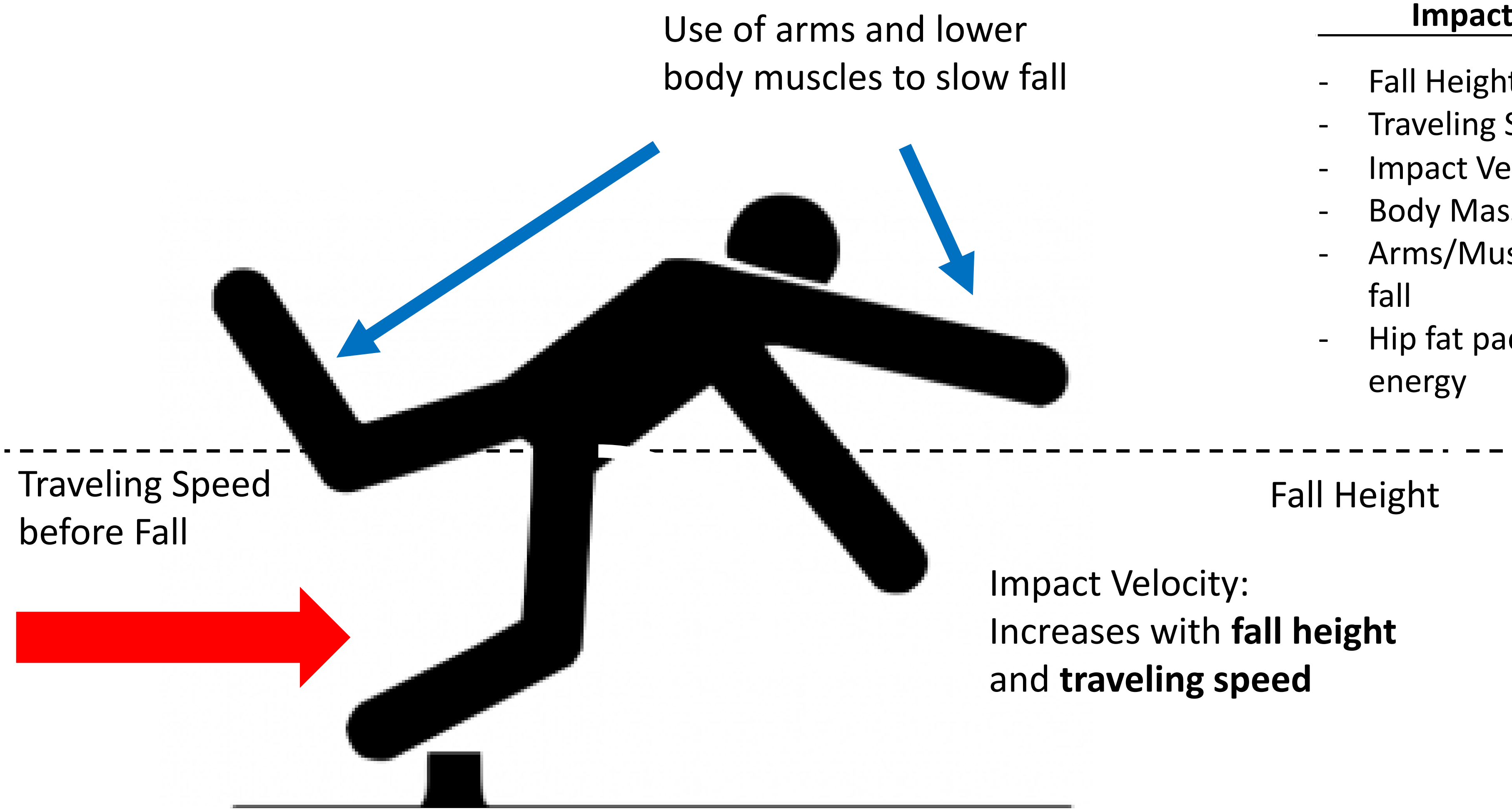
1. **Hip Quantitative Computed Tomography (Hip QCT)** –
   - Pilot study (n=10 ISS astronauts): Use of QCT to monitor the *complete* restoration to baseline levels and to *detect a clinical trigger*, i.e, failure to recover hip trabecular BMD by 2 years after return to Earth.
   - Clinical Response: Possible intervention to mitigate risk for premature fragility fractures [Long-term health **LTH** fracture risk] since this deficit predicts hip fracture in the aged.*

2. **FE Strength Cutoff** –
   - Explored the potential of using hip bone strength, estimated from FE Models of QCT hip scans, as a new index of *bone health* in long-duration astronauts.
   - Evaluated changes in hip bone strength is ISS astronauts.
   - Generated a database of FE hip strengths from aging Earth-based population to discern a hip strength value that is associated with hip fractures due to age-related bone loss.

* Black, et al. JBMR;2008; Bousson et al. JBMR;2011

**synonymous with “Load Capacity” or “Force to Failure” “Biomechanical Competence.”

# Mechanical loads to hip with Falls were estimated by Digital Astronaut Project [DAP] integrating the following factors.*



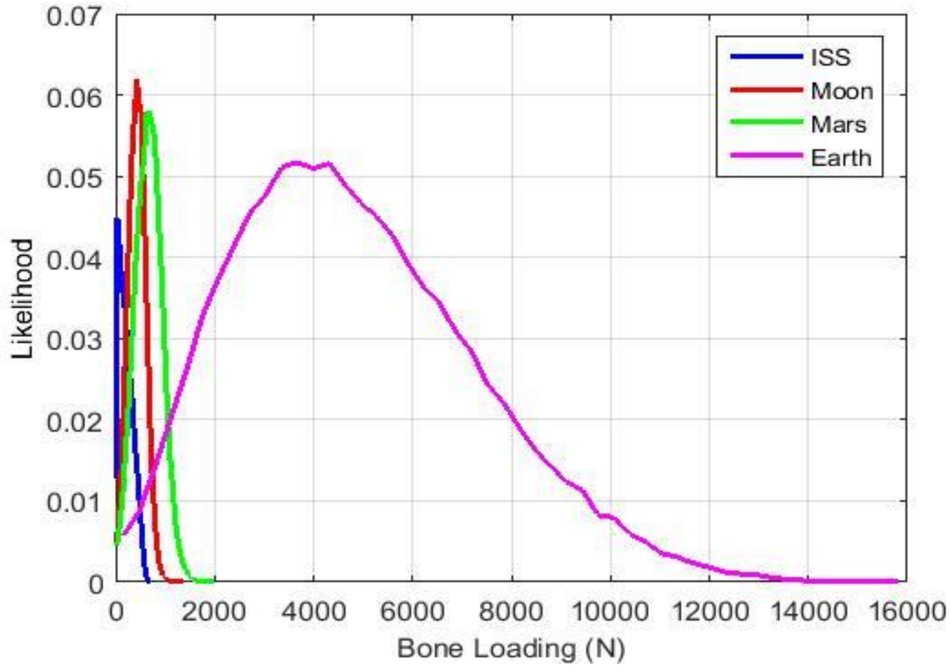

**Factors Affecting Hip Impact Force**

- Fall Height
- Traveling Speed
- Impact Velocity
- Body Mass
- Arms/Muscles to slow fall
- Hip fat pad absorbs energy

*Factors do not account for physiological deconditioning due to spaceflight.

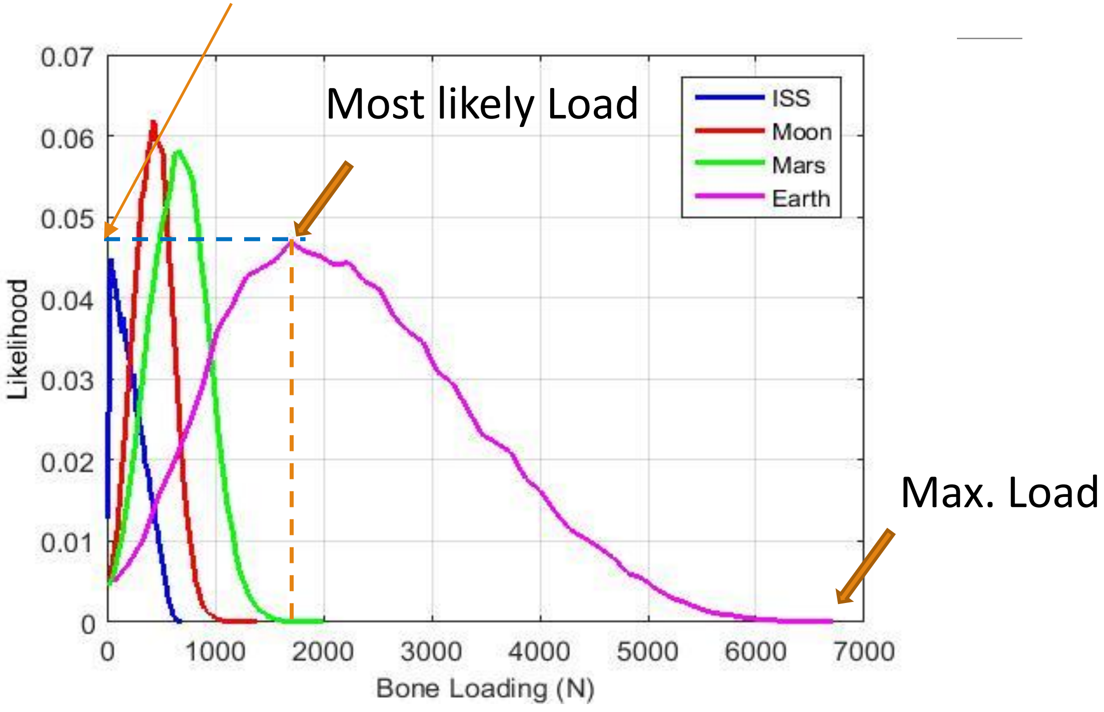
Figure courtesy of Scott Lenfest (TAMU) based upon DAP Modeling Nelson et al. Ann Biomedical Eng., 2009.

# Methods previously described were used to **estimate distribution of mechanical loads to hip* during Design Reference Missions (DRMs)** and on Earth.




All Load Distributions including **High Energy** Falls (>4 kN) (e.g., football, skiing)

~4700 our of 100,000 Falls




**Load Distributions with Low Energy** Falls (1-4 kN) (e.g., tripping)

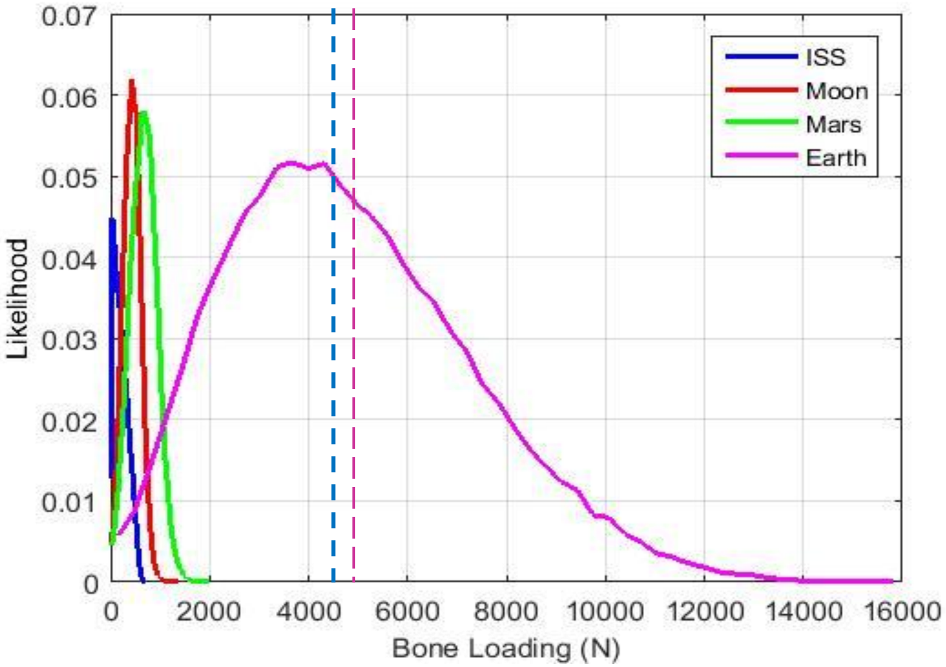
(Data figures courtesy of B. Lewandowski, PhD , DAP. Nelson et al. Ann Biomedical Eng., 2009)

* **with 100,000 Fall events**

# Mean FE hip Fall Load Capacity (preflight and postflight) for ISS astronauts (n=17) all with access to ARED* over ~ 6-month spaceflight duration.

**NO HAZARD FOR OVERLOADING ASTRONAUT HIP DURING DRMS (LOW G)**

**6mos Postflight** ARED **4440+605 N** **Preflight** (n=17) **4555+673 N NL Fall**

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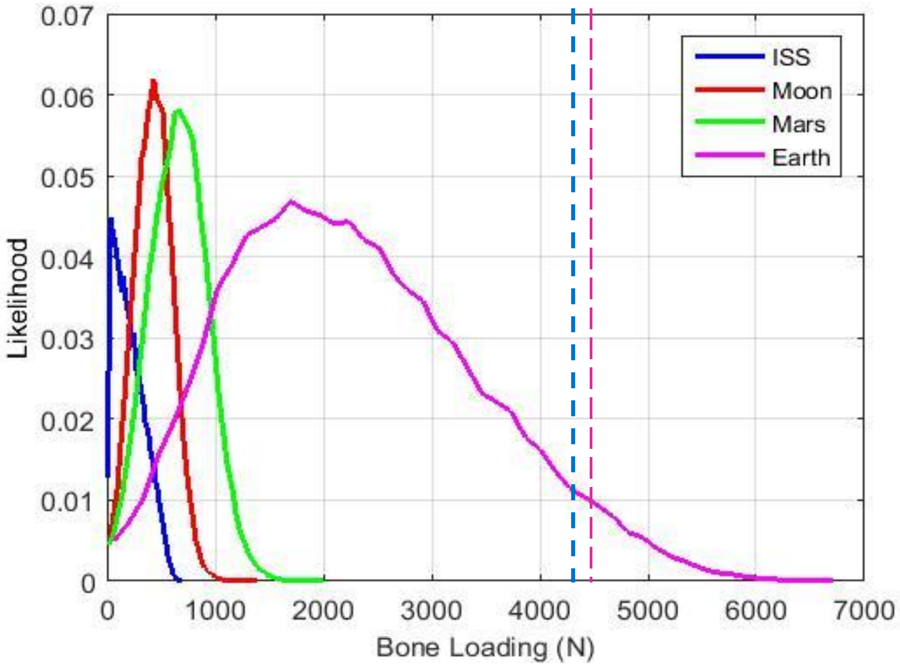



**Load Distributions with Low Energy** Falls (1-4 kN) (e.g., tripping)

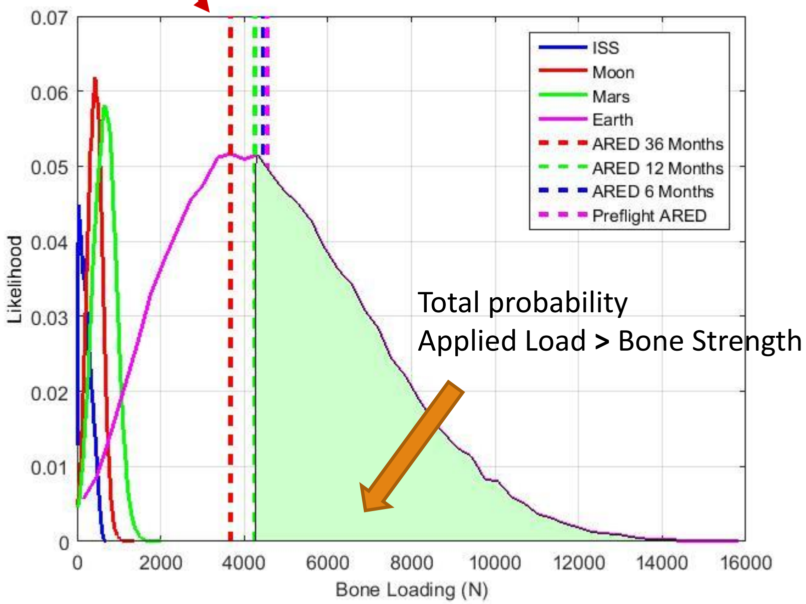
*n=7 Sprint Study and n=10 ARED

(Data figures courtesy of B. Lewandowski, PhD , DAP. Nelson et al. Ann Biomedical Eng., 2009)

# No hazard for overloading astronaut hip during DRMs
# EVEN AFTER 12 OR 36 MONTHS IN SPACE
# (averaged monthly decline* in FE strength, -24N/month)

**12mos Postflight** ARED
**4262 N**

**36mos Postflight** ARED
**3675 N**



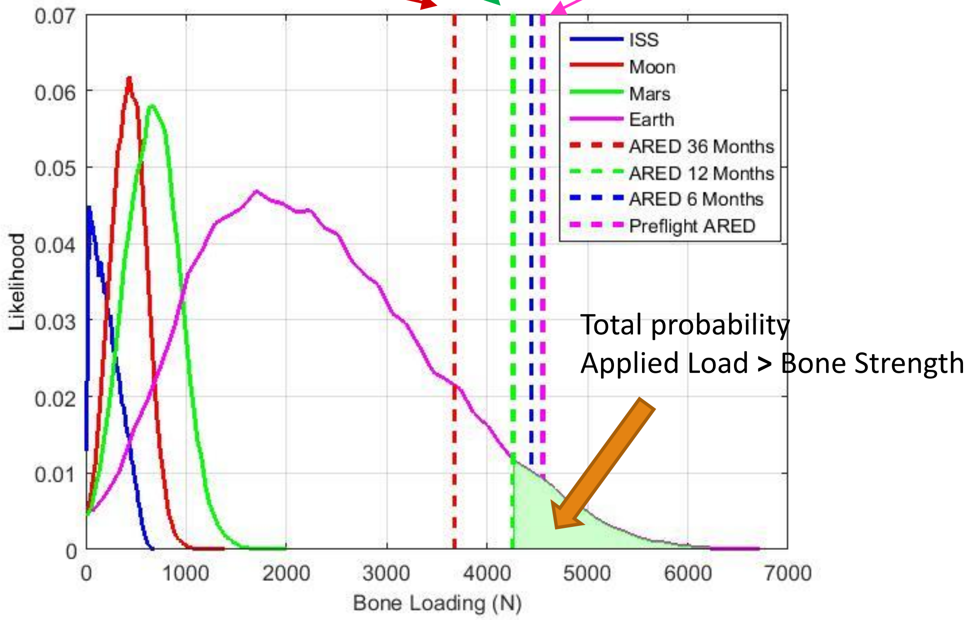

All Load Distributions including **High Energy** Falls (>4 kN) (e.g., football, skiing)

**6mos Postflight** ARED
**4440±605 N**

**12mos Postflight** ARED
**4262 N**

**36mos Postflight** ARED
**3675 N**

**Preflight** (n=17)
**4555±673 N NL Fall**




**Load Distributions with Low Energy** Falls (1-4 kN) (e.g., tripping)

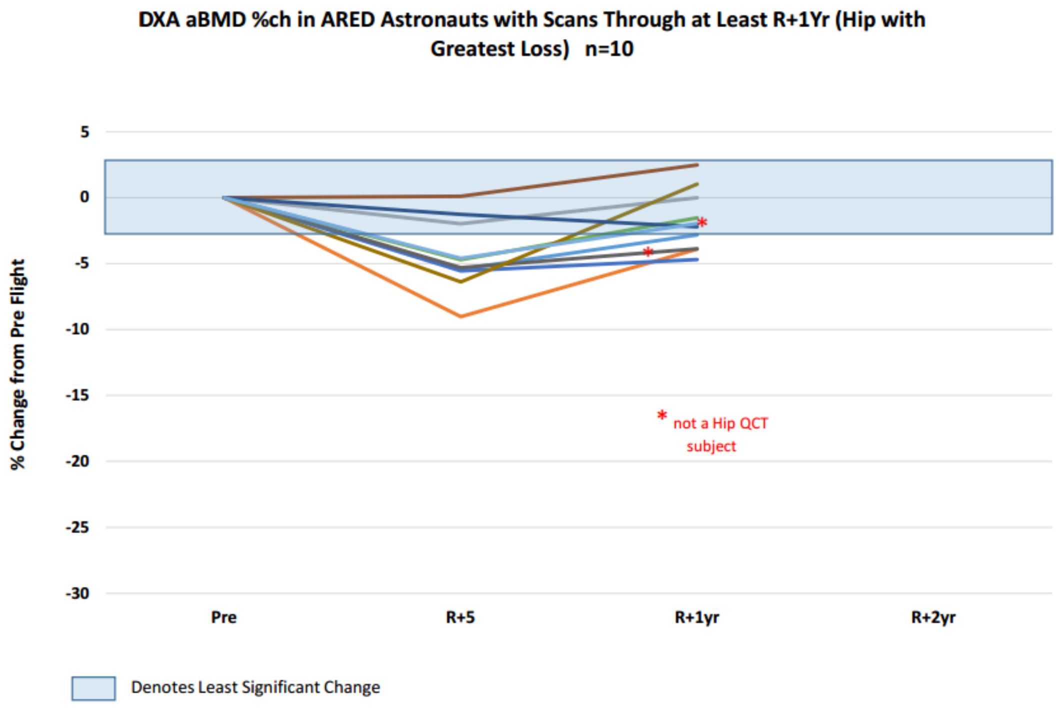
(Data figures courtesy of B. Lewandowski, PhD , DAP. Nelson et al. Ann Biomedical Eng., 2009)

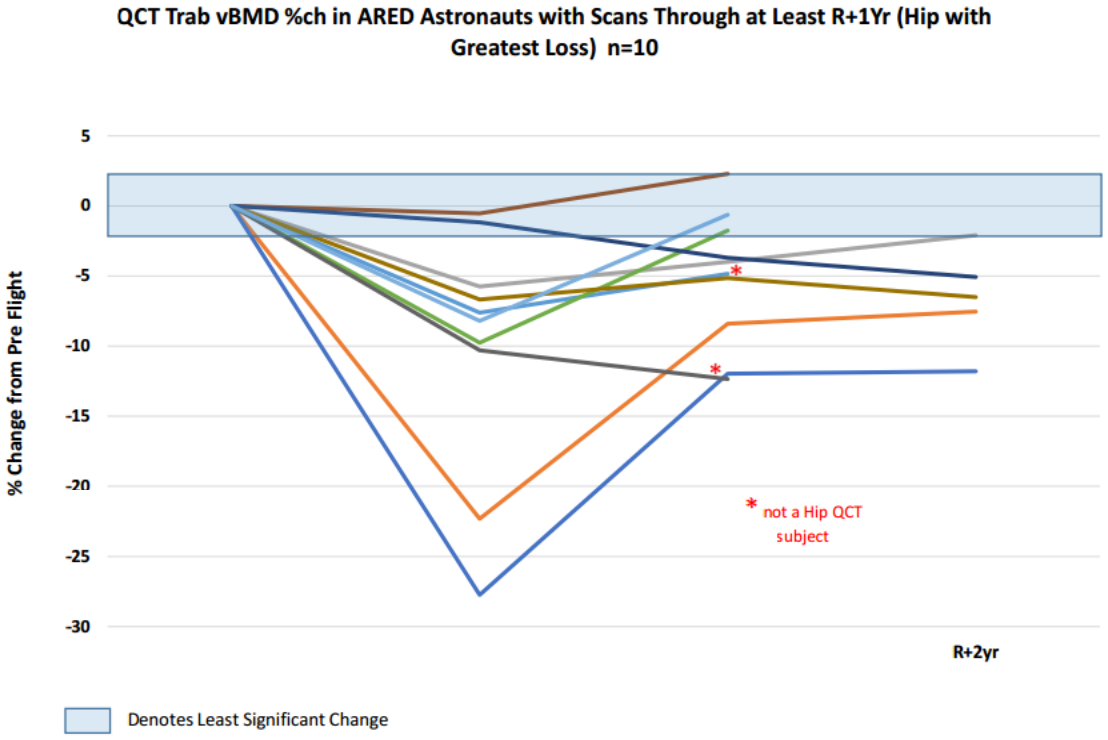
*DRM= Design Reference Mission*

* Individual monthly declines of 17 astronauts, averaged.

# Hip QCT (n=10 astronauts): Monitoring recovery with DXA measurement of areal BMD and with QCT trabecular vBMD of hip.

# DXA fails to assess for clinical trigger and misses those who may need intervention to mitigate LTH fracture risk (n=2 not in Hip QCT study).




*Note: Replaced the bisphosphonate-treated subjects (n=2) to focus on exercise countermeasure effect only.

# Limitations

1. All models are only as good as the input data: i)*Modeling bone strength, ii) Modeling applied loads to hip.*
2. The probability of fractures due to repetitive bone loading (i.e., <u>stress fractures</u>) or due to moving masses (i.e., <u>crush fractures</u>) are not included in this analysis. *Probability of fractures could be underestimated.*
3. The determination of Bone Strength by FE modeling is for a specific load orientation (e.g., posterolateral falls). Loads to hip with falling can occur over broad range of orientations. *Probability of overloading could be underestimated.*
4. QCT hip technology cannot resolve the effect of rapid bone loss on trabecular bone microarchitecture (data not yet acquired).

# Conclusions

**Based upon presented data:**

1. **The likelihood of an astronaut hip fracture due to a fall during ISS/moon/Mars missions is < 0.1%.**

2. **DXA hip scans as sole surveillance will not detect full restoration from spaceflight-induced losses in bone mass and the trigger for intervention to mitigate LTH fracture may be missed.**

3. **The disruption of hip trabecular bone microarchitecture is a concern but currently cannot be confirmed with DXA or QCT imaging technology.**

# Recommendations

1. **QCT hip scans should be performed in all astronauts for risk surveillance.** ***This recommendation has concurrence from Bone RCAP.***

2. **QCT data shall be translated to hip bone strength to <u>enhance</u> the assessment of fracture risk after return to Earth (e.g., identify activities that could overload bones).**

3. **Technologies to assess bone microarchitecture for deeply embedded bones of hip and spine are being solicited through NRAs (NASA Research Announcements).**

# Acknowledgments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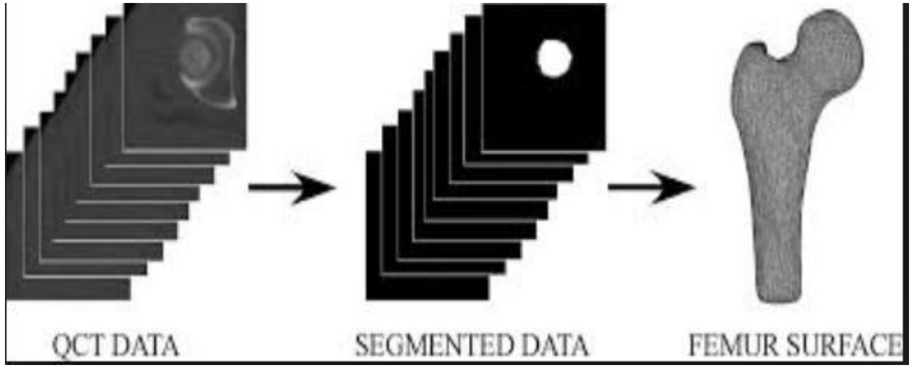
# Back-up visuals

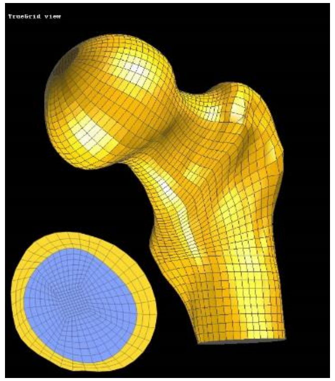
# QCT enables Bone Strength Determination (“Load Capacity” “Force to Failure”)

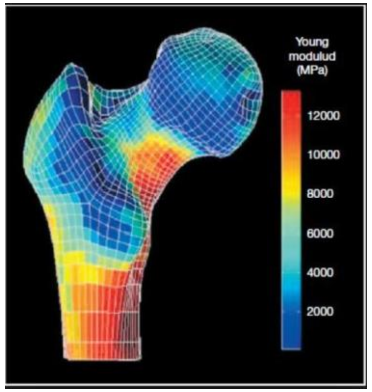
## GENERATING FINITE ELEMENT MODELS

Virtual Loading

**QCT** → **Quantify mg/cm ³ (volumetric BMD)** → **Contour and reconstruct whole bone** → **Mesh bone contour** → **Predict Bone Strength (kN)**





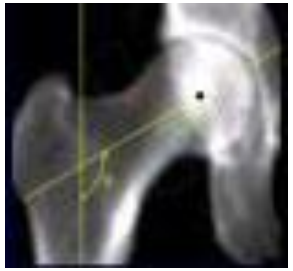

**$R^2$=.84**

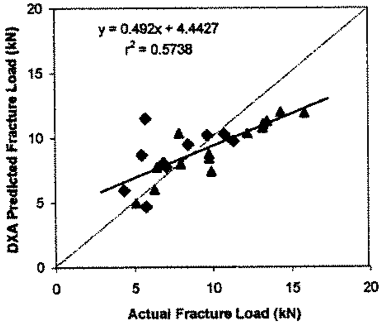
Cody D et al. J Biomech, 199. **32**(10): p. 1013-20

# Steps to Bone Strength Determination ("Force to Failure")

DXA → In vitro BONE STRENGTH ANALYSIS → PREDICT BONE STRENGTH (kN) from areal BMD

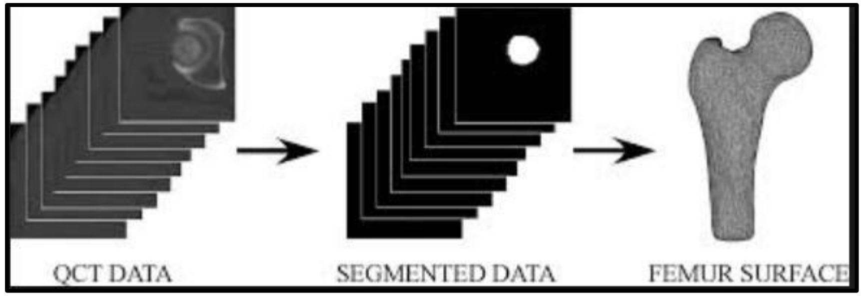
$R^2$=.55

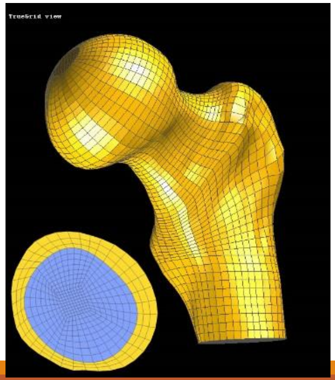


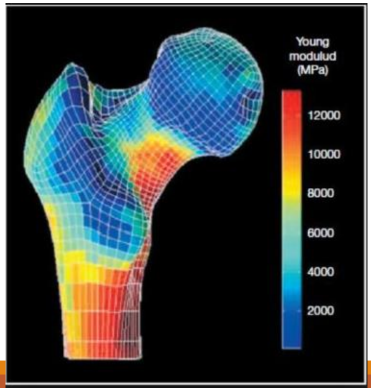



$R^2$=.84

QCT → GENERATE FINITE ELEMENT MODELS → ANALYZE FINITE ELEMENT MODELS → PREDICT BONE STRENGTH (kN)



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