Cutting Edge Training and Testing Technologies for Occupations with Unique Physical Demands

Optimizing Astronaut Performance For Long Duration Spaceflight

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Exercise Physiology & Countermeasures

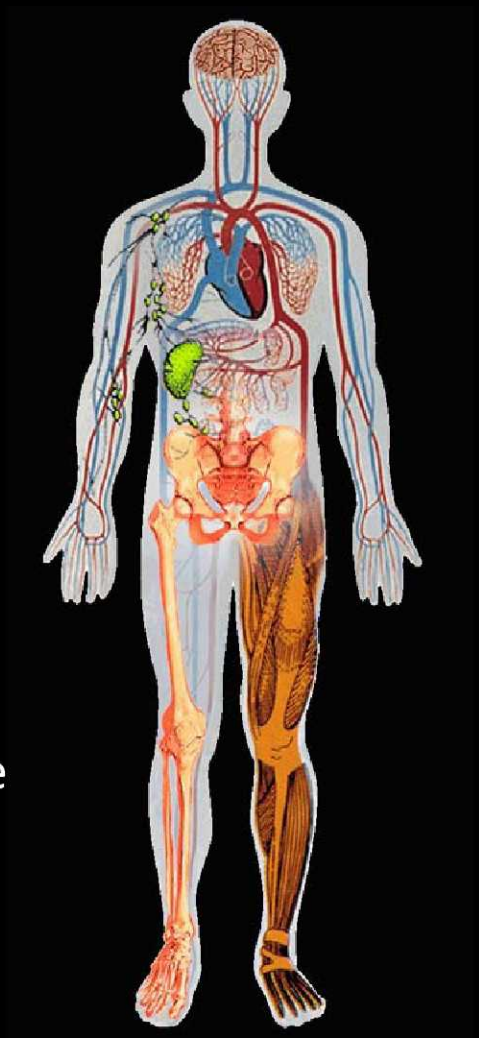
Physiological Changes Associated with Space Flight

Bone

- ↓ Bone mineral content
- ↓ Bone mineral density
- ↑ Urinary calcium
- ↑ Renal stone risk

Skeletal Muscle

- ↓ Skeletal muscle mass
- ↓ Skeletal muscle strength
- ↓ Skeletal muscle endurance
- ↓ Skeletal muscle capillary density



Neurosensory

- ↓ Vestibular disturbances
- ↓ Space motion sickness
- ↓ Sensorimotor function
- ↓ Postural & locomotor stability

Cardiovascular

- ↓ Fluid volume
- ↓ Orthostatic tolerance
- ↓ Aerobic capacity
- ↓ Arrhythmias

ISS Exercise

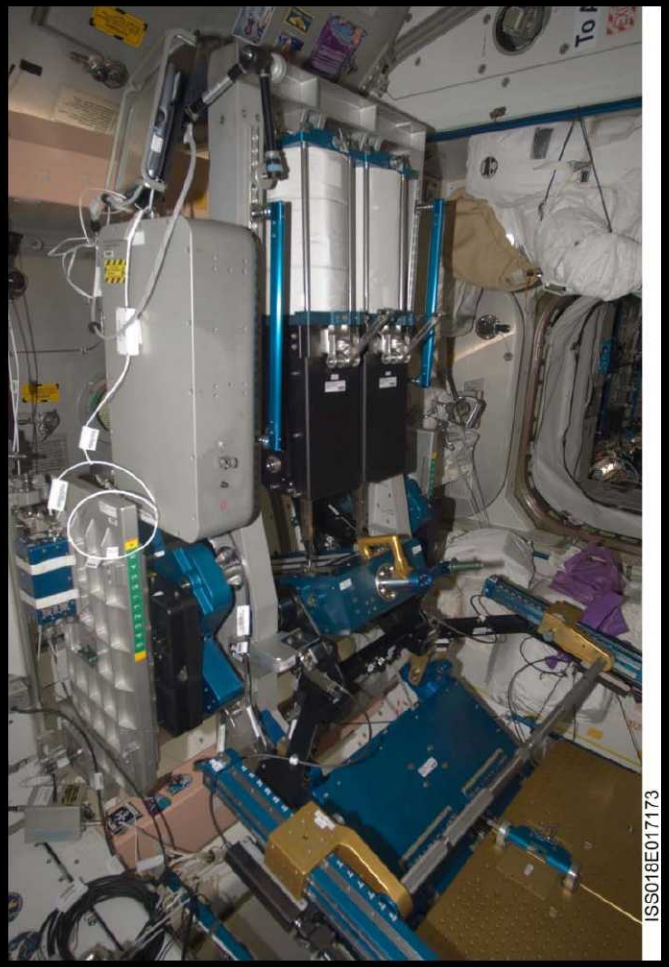
- 2.5 hrs/day, 6 days/wk
- Resistance exercise
  - iRED now ARED
  - Historically high reps low loads
- Aerobic exercise
  - TVIS & CEVIS
  - 30 min continuous at ~70% HRmax
  - Some moderate intensity intervals

Limitations of ISS Exercise Hardware

- iRED
  - Maximal load 300 lbs
  - Elastic bungee resistance
  - not constant
  - Limited eccentric
  - component

New ISS Hardware - ARED

- More exercises (29 different ones)
- Instrumented for data acquisition
  - Sets
  - Reps
  - Ground reaction forces
  - Load at the bar
- Improved loading
  - 600 lbs
  - Ecc-Con Ratio ~90%
  - Constant load
  - Simulated inertia (free weight)



ARED Video

Limitations of ISS Exercise Hardware

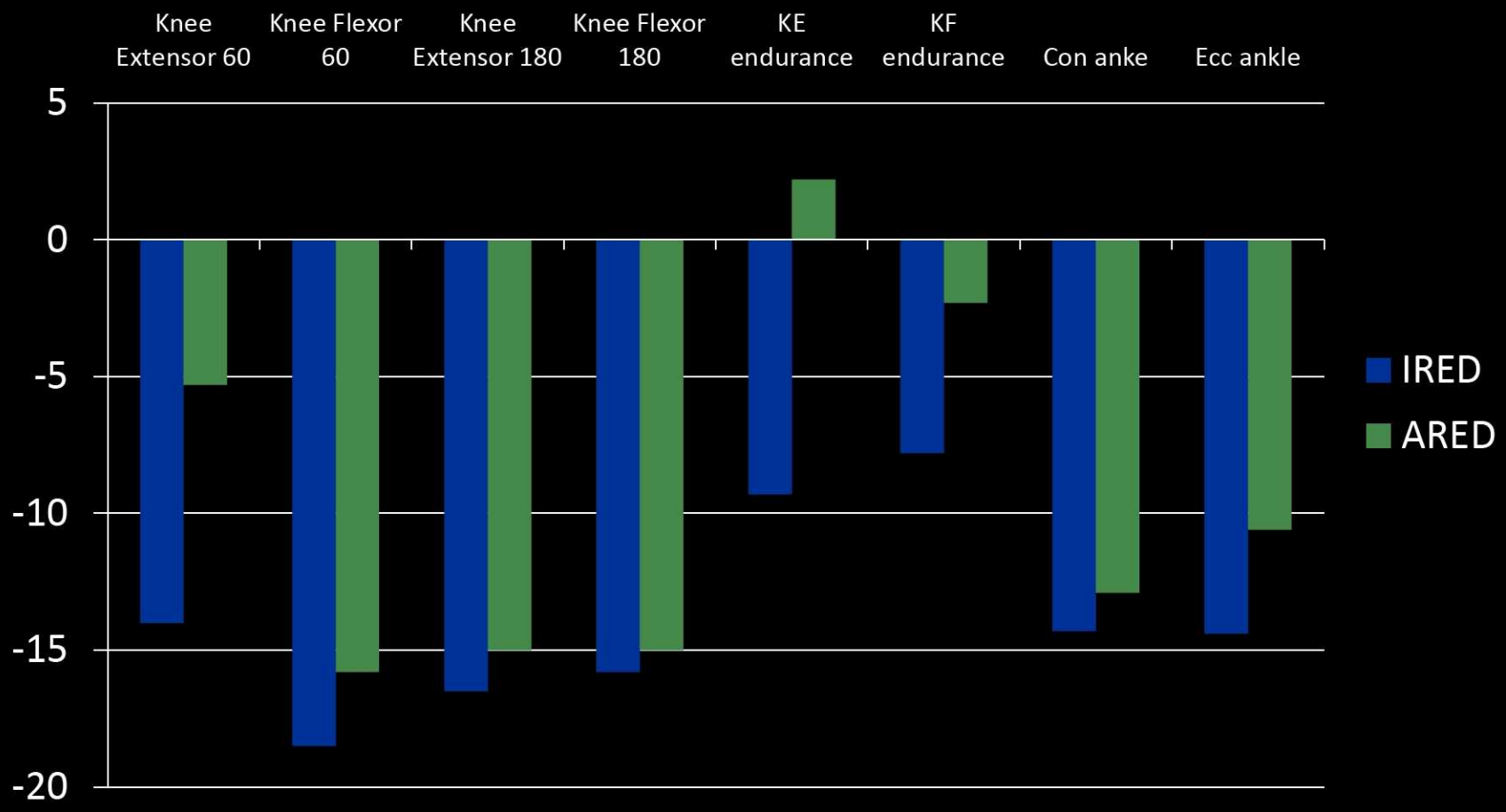
- CEVIS
  - Maximal load 300 Watts
- TVIS
  - Speed limitations
  - Subject loading limitations

New Exercise Equipment

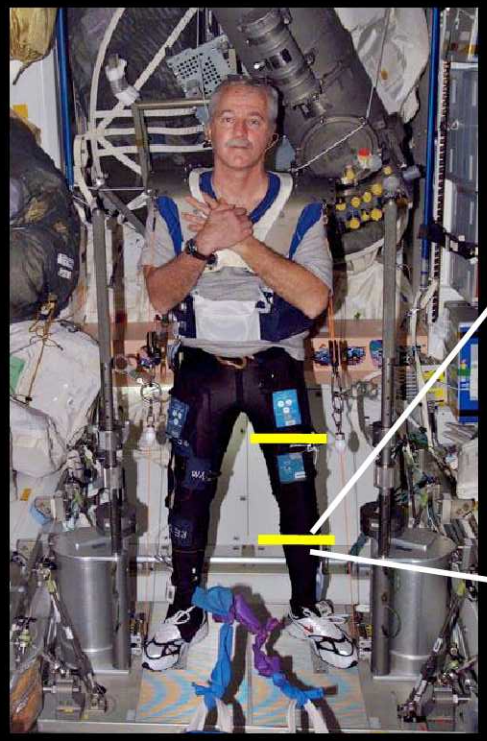
- **T2 treadmill**
  - New loading system in development
  - Instrumented
    - Ground reaction forces
    - Impact loads
  - Improved speed

T2 video

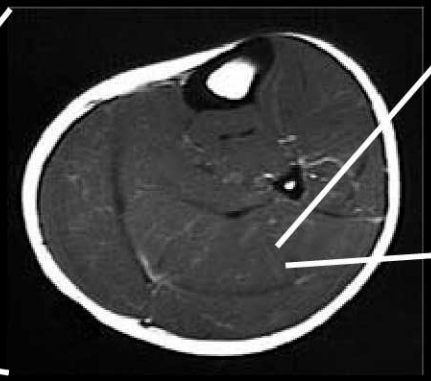
Isokinetic Muscle Function



Muscle Biopsy
Whole Muscle → Cellular Level

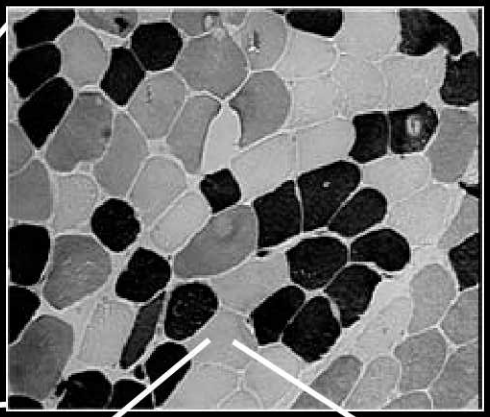


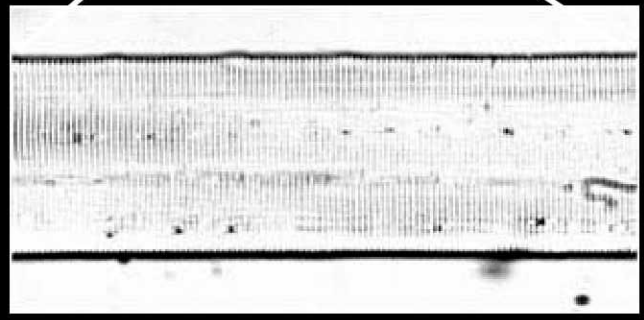
Exercise on the ISS



MRI Scan
Whole Muscle Size
(15% loss on ISS*)

Muscle Biopsy Sample

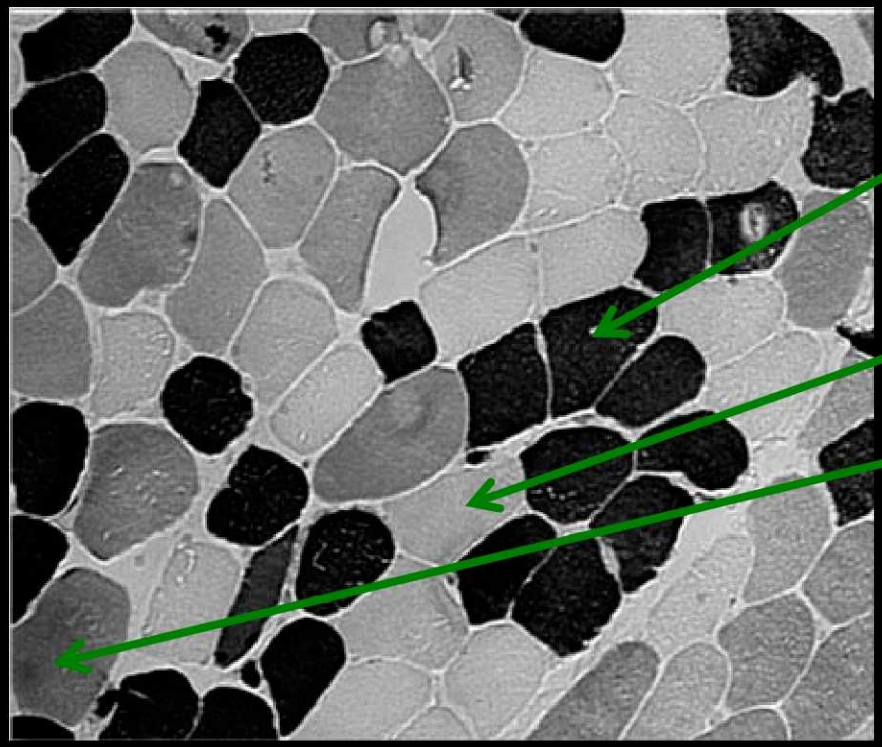




One Muscle Fiber

* *J Appl Phyiol* 106: 1159-68, 2009 and ASEM 81: 91-102, 2010

Muscle Biopsy



Slow-Twitch Fibers
Endurance and Posture

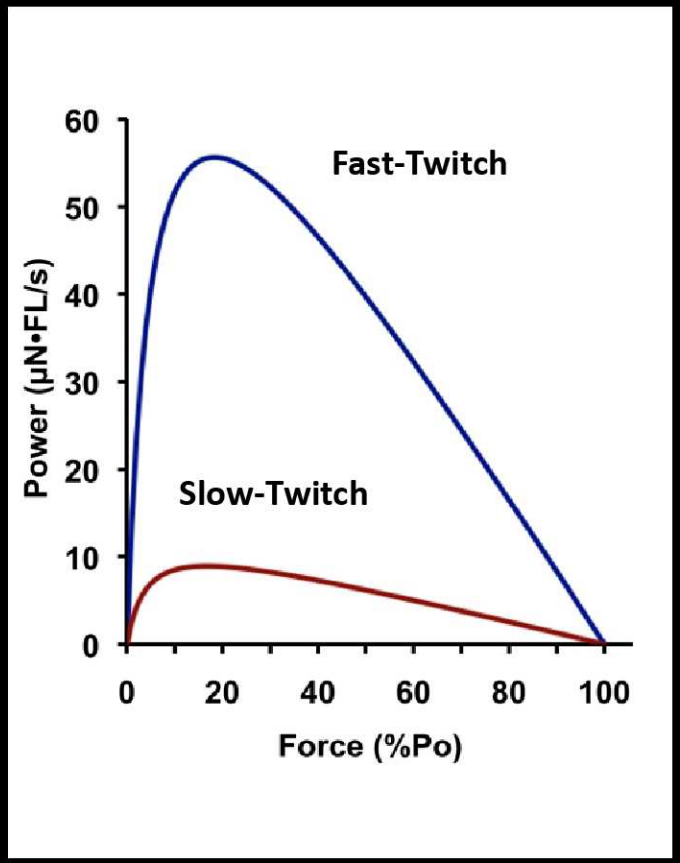
Fast-Twitch Fibers
Explosive Power
Movements

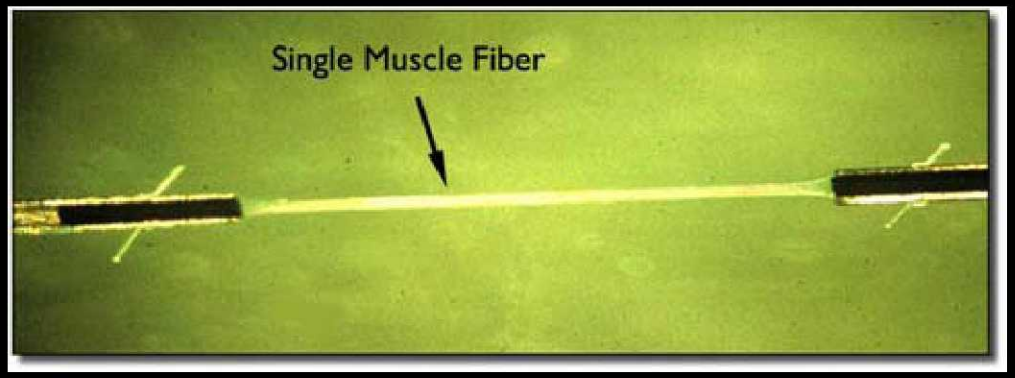
ISS Findings (Increment 5-11):

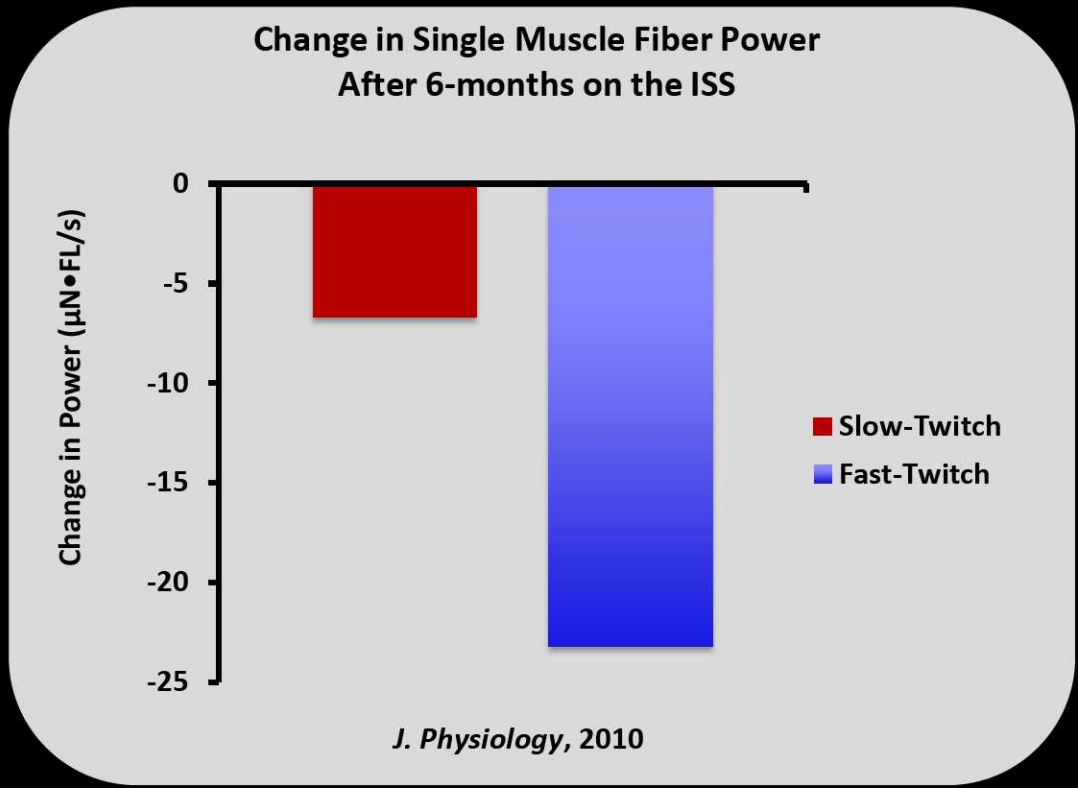
12-17% shift in fiber type
Slow → Fast Transition

J Appl Phyiol 106: 1159-68, 2009

Single Muscle Fiber Power

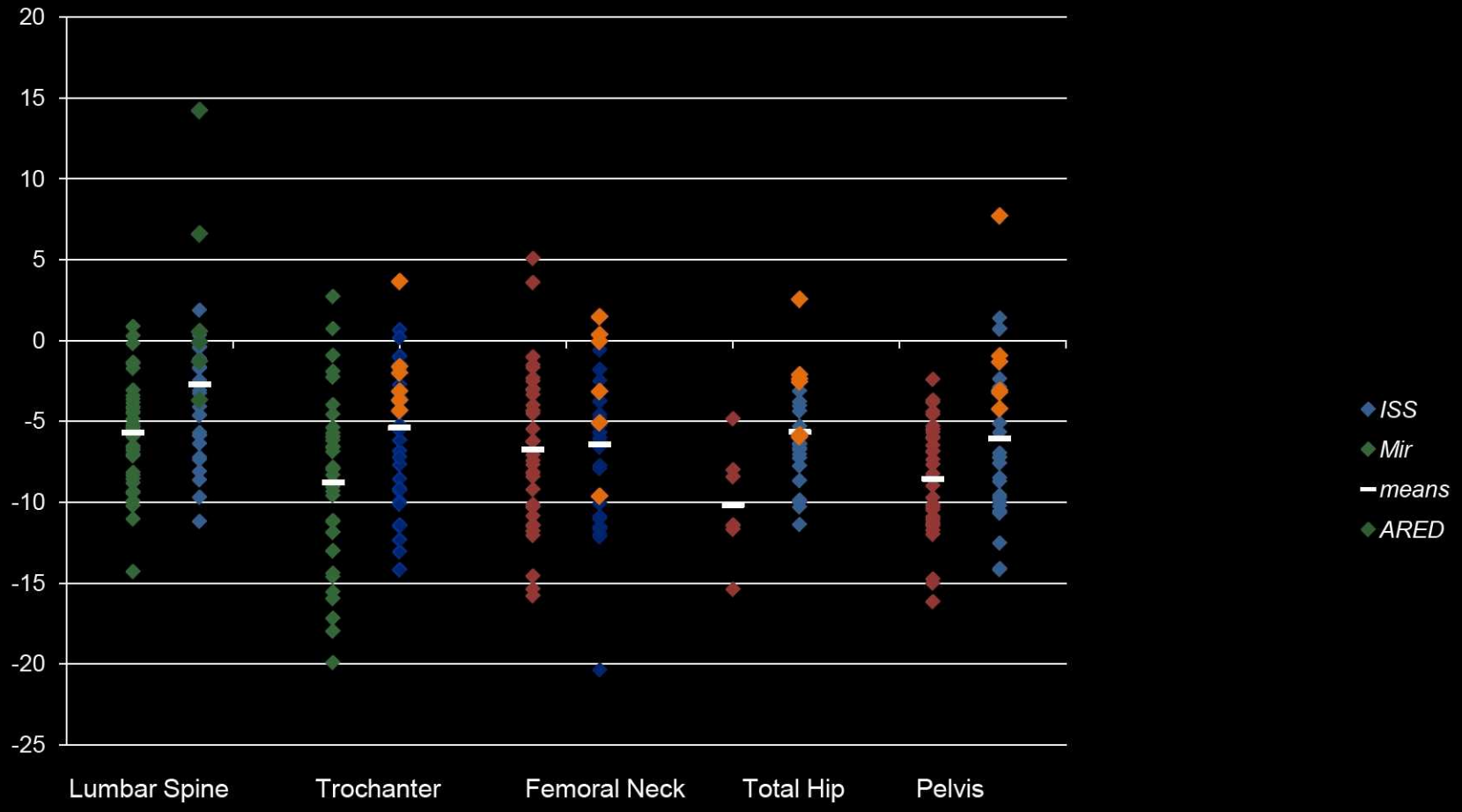






Changes in BMD

% change/6 months



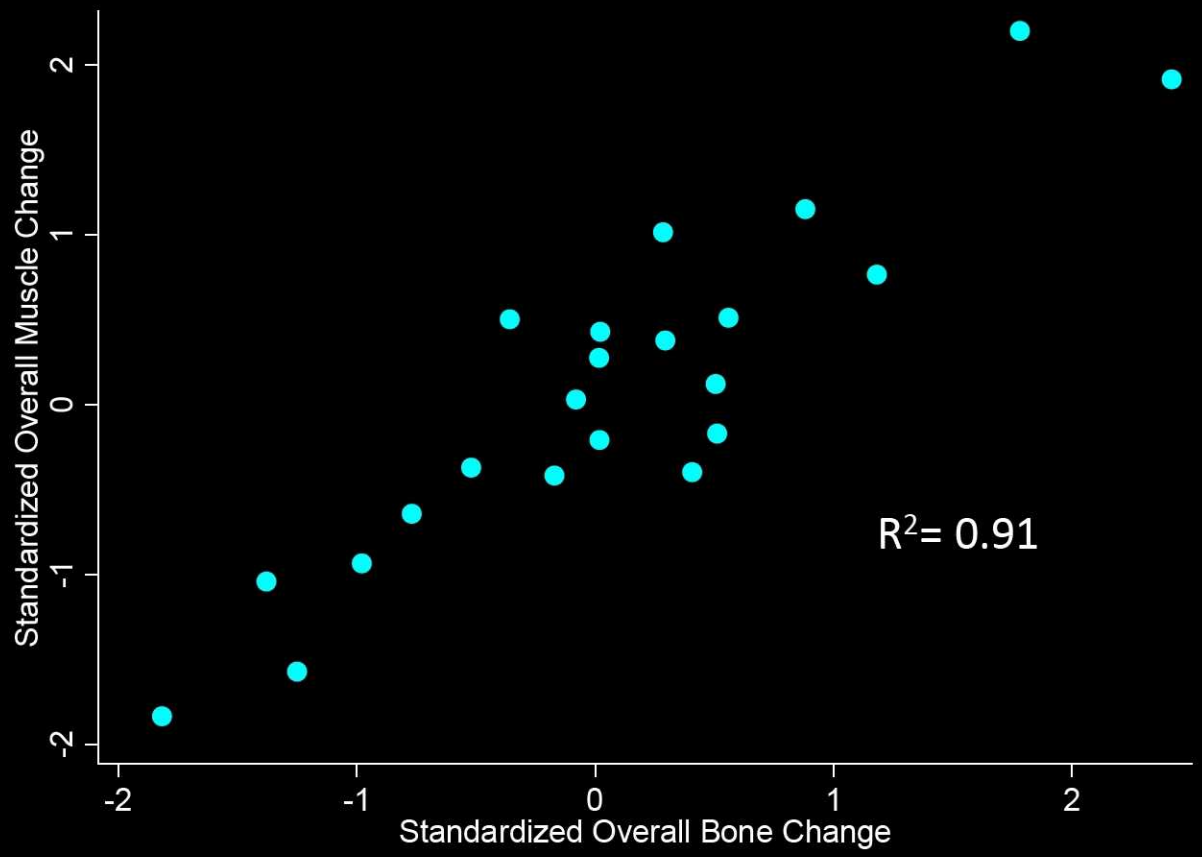
QCT After Flight: Greater percentage loss vBMD in trabecular bone compartment (n=16 ISS)

NOT detectable by DXA

LeBlanc, J M Neuron Interact, 2000;
Lang , J Bone Miner Res, 2004;
Vico, The Lancet 2000

Index DXA	%/Month Change ± SD	Index QCT	%/Month Change ± SD
aBMD Lumbar Spine	1.06±0.63*	Integral vBMD Lumbar Spine	0.9±0.5
		Trabecular vBMD Lumbar Spine	0.7±0.6
aBMD Femoral Neck	1.15±0.84*	Integral vBMD Femoral Neck	1.2±0.7
		Trabecular vBMD Femoral Neck	2.7±1.9
aBMD Trochanter	1.56±0.99*	Integral vBMD Trochanter	1.5+0.9
*p<0.01, n=16-18		Trabecular vBMD Trochanter	2.2+0.9

Muscle and Bone Change Similarly



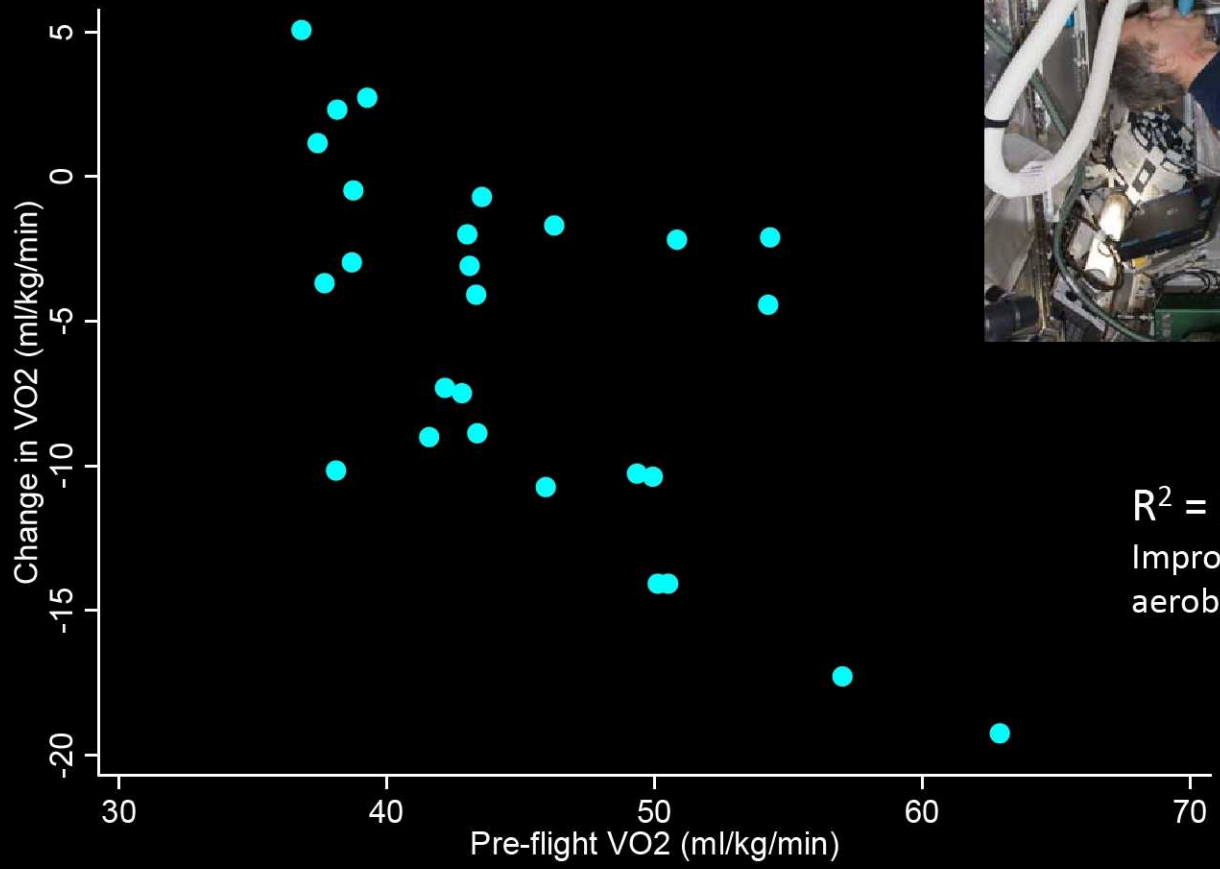
Muscle contributors

Con & ecc ankle plantar flexion
Con & ecc ankle dorsi flexion
Hamstring total work
Hamstring isokinetic strength
QF total work
QF isokinetic strength

Bone Contributors

Lumbar spine BMD
Femoral neck BMD
Pelvis BMD
Calcaneous BMD
Whole body BMD

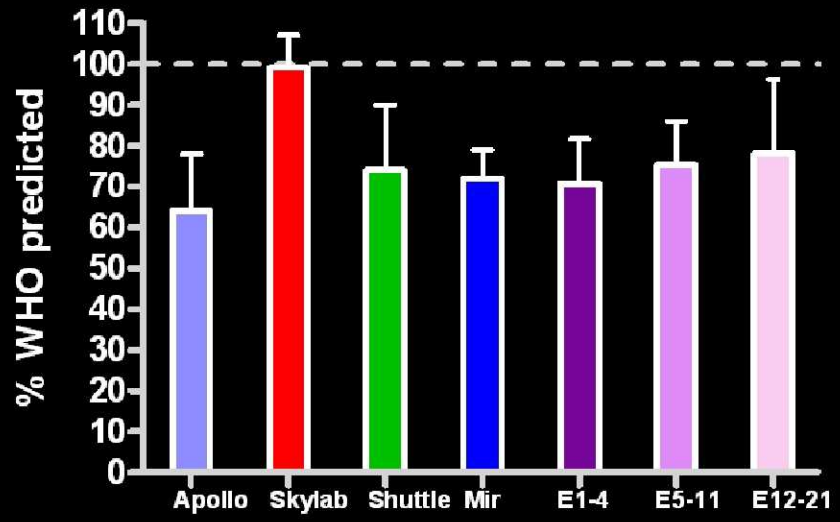
Cardiovascular Fitness

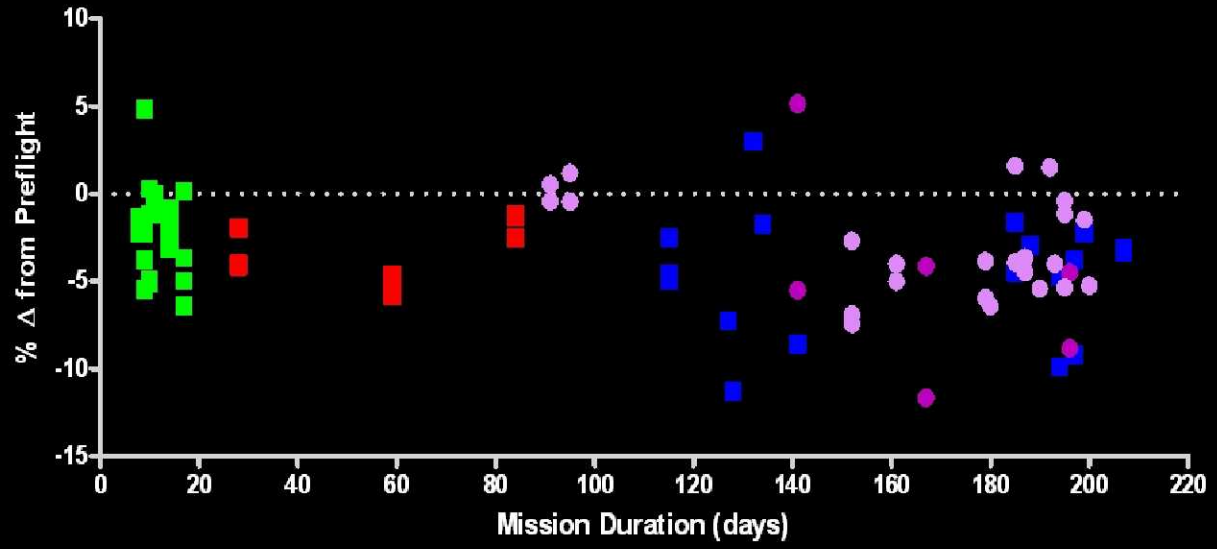


$R^2 = 0.44$

Improves to ~0.6 when min/week of aerobic exercise are considered

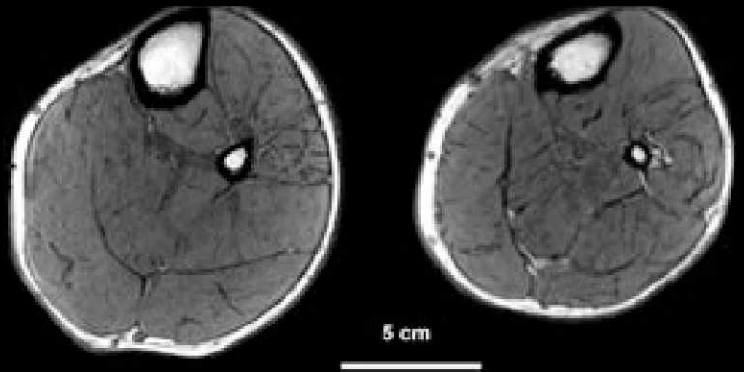
Energy Availability





New Exercise Prescription Study

- New type of hybrid study part operations part research
- Addresses 4 risks and 5 gaps in HRP Integrated Research Plan
- Risk of Reduced Physical Performance Capabilities Due To Reduced Aerobic Capacity
- Risk of Accelerated Osteoporosis, Fracture
- Risk of Impaired Performance Due To Reduced Muscle Mass, Strength and Endurance Gap
  - M7: Can the current in-flight performance be maintained with reduced exercise volume?
  - Gap M8 What is the minimum exercise regimen needed to maintain fitness levels for tasks?
  - Gap M9 What is the minimum set of equipment needed to maintain those (M8) fitness levels?



Integration of Aerobic & Resistance

Resistance	35-60 min		35-60 min		35-60 min		
Aerobic Interval		32 min		15 min		35 min	
Aerobic Continuous	30 min		30 min		30 min		

Note: Time savings up to 3 hours/week compared to current exercise time
At least 4 hrs, preferably 8 hrs separating exercise sessions

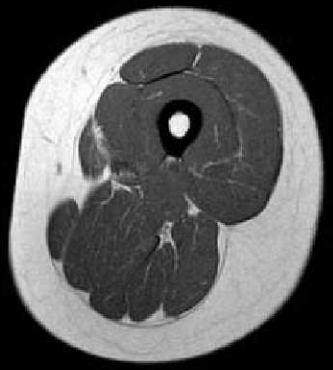
New Prescription & New Tests

- **Basic Changes to the Typical ExRx**
  - Higher intensity, less exercise time
  - 3 days/week instead of 6 days/week resistance exercise
    - 3-12 RM periodized
  - Aerobic exercise every day
    - Also periodized
    - 30 min continuous on resistance days
    - High intensity intervals on alternate days (15-35 min)

- **More comprehensive physiological outcomes**
  - Typical medical tests
  - Muscle CSA (US/MRI)
  - Full battery of muscle function
  - VO_2max & ventilatory threshold
  - Muscle biopsy option

Outcome Measurements

- Muscle
  - Pre/In/Post-flight assessment of muscle size (MRI / Ultrasound)
  - Muscle Function
    - Strength, power, endurance, CAR, steadiness
  - Muscle biopsy
    - Single fiber size, contractile function, type, capillary density, metabolic enzymes
- Bone
  - Pre/Post DEXA and qCT (hip, spine)
- Cardiovascular
  - Pre/In/Post-flight VO_2max & HR response to submax load
  - Ventilatory threshold pre/post-flight
  - Cardiac function with ultrasound



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