Integrated Resistance and Aerobic Training Study- Sprint

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Background

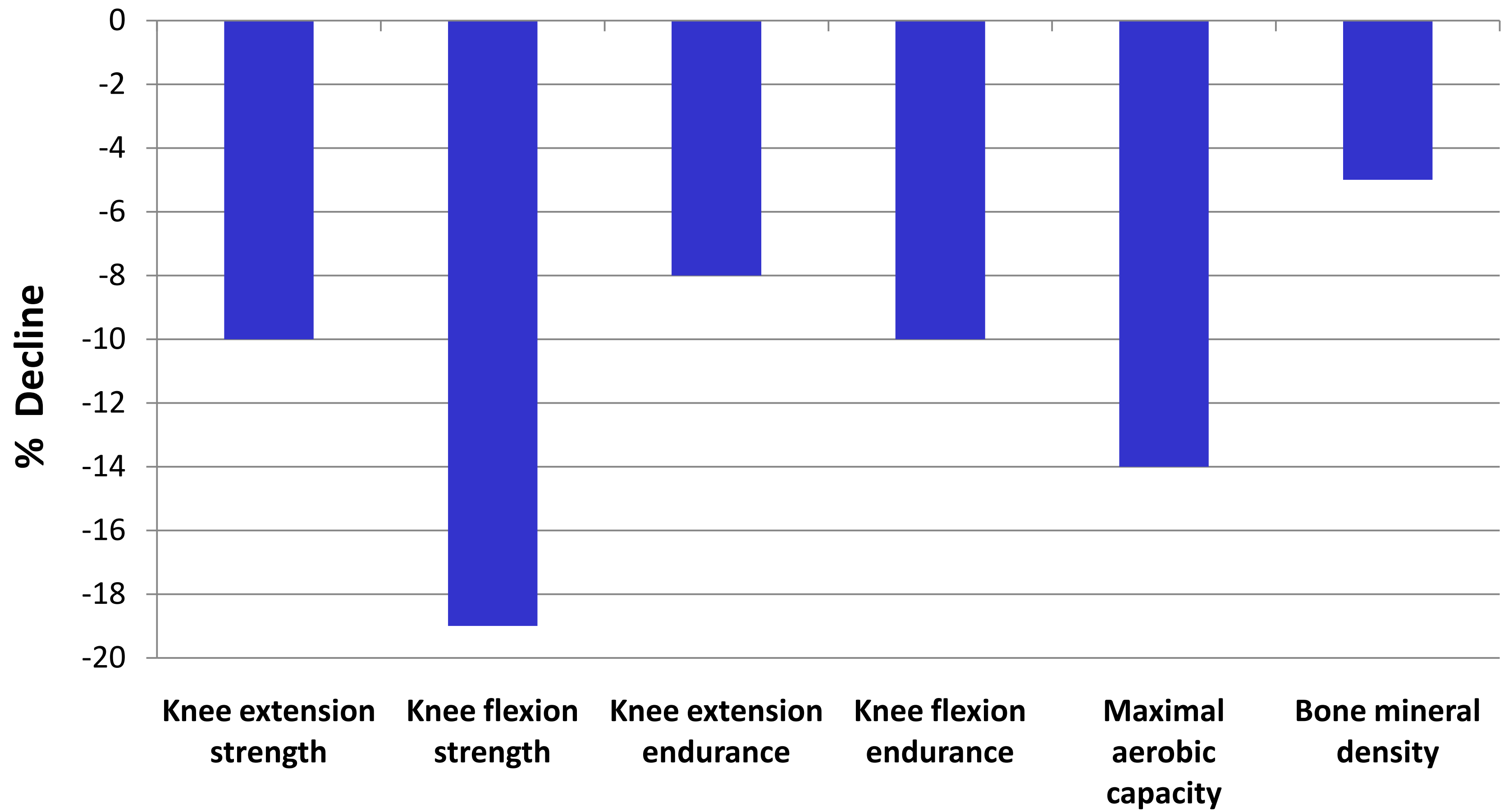
Space flight causes reductions in fitness/health:

- Cardiovascular - reduced VO_2max, cardiac output
- Bone – reduced bone mineral density
- Muscle - reduced mass, strength and endurance

Exercise is the primary countermeasure to protect against these changes and was made operational before completely mature; research continues to identify most effective/efficient exercise programs.

Crew medical tests (cardio, muscle, bone) do not yield sufficient information to fine tune the effectiveness of exercise programs, thus there is a need for more detailed testing aimed at identifying the most effective training program.

Fitness declines with ISS missions (n=24)



Background

- NASA has spent millions of dollars over past decade to fund new exercise equipment and research on exercise effectiveness.
- Ground research clearly shows that intensity is the most important factor related to maintenance of fitness
  - Duration and frequency can be dramatically reduced only if intensity is kept high
- ARED and T2 allow for more variety and higher intensities

Background

- June and October 2008 workshops identified the need for an optimized exercise prescription.
  - ASCR, ExPC, HRP management, flight surgeons, medical operations, external experts in muscle, bone and cardiovascular function.
- Major recommendations
  - Higher intensity, less frequent resistance exercise
  - More variety of resistance exercises
  - Alternate days of moderate intensity continuous aerobic exercise with higher intensity interval aerobic exercise
  - Monitor in-flight exercise performance using instrumented hardware
  - Include more robust physiological outcome measurements to document the efficacy of the exercise program.

Objective

- Obtain detailed information about crew physical fitness pre- and post-flight.
  - Participation involves pre- and post-flight testing (modifications to standard medical & new tests).
- Evaluate new evidence based exercise prescription with higher intensity, lower duration and frequency.

Participation Options

- Active subject - Full participation of all pre-, in-, and post-flight data collection and in-flight exercise program
- Control subject - Pre- and post-flight testing only
- Data Sharing subject – Agree to share medical pre, in, and post bone and exercise data
- Muscle biopsy

In-flight exercise program

- Higher intensity, lower frequency and duration
- Muscle
  - Bedrest and unloading studies show 2-3 days/week of training is sufficient if the contractions during resistance exercise are maximal or nearly maximal
  - Aerobic intervals optimal for affecting muscle aerobic metabolism/endurance
- Bone
  - Evidence suggests multiple daily sessions required
  - High magnitude and rate of strain
  - Site specificity
- Cardiovascular
  - Need high intensity, best achieved with intervals

Integration of Resistance and Aerobic

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
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

Sprint Aerobic Intervals

- **Short Sprint** - 10 minute warm up at 50% of HRmax, followed by 7-8 sets of near-maximal exercise for 30 seconds, followed by 15 seconds rest. Increase load after 9 sets (Burgomaster et al., 2008; Gibala & McGee, 2008; Gibala et al., 2008; Tabata et al., 1996)
  - Increases mitochondrial function, peripheral cardiovascular adaptations such as muscle enzymes and capillary density.

- **2 minute** - 5 minute warm up at 50% VO_2max, followed by 6x2 minute stages at 70, 80, 90, 100, 90%, 80% VO_2max. The first 5 stages are separated by 2 minute active rest stages at 50% VO_2 max. The final stage is a 5 min active rest at 40% VO_2max. (Greenleaf et al., 1989)
  - Maintain maximal aerobic capacity, similar protocol well tolerated on ISS

- **4 minute** - 5 minute warm up at ~50% HRmax, followed by intervals of exercise at 90% HRmax. The exercise intervals will be 4x4 min bouts, with 3 min active rest periods. (Helgerud et al 2007)
  - Cardiac adaptations, cardiac output and stroke volume

Sprint Resistance Exercise

	Day 1	Day 2	Day 3
	Squat, Bench Press, Romanian Dead Lift, Upright Row, Heel Raise	Dead lift, Shoulder Press, Bent-over Row, Single Leg Squat, Heel Raise	Front Squat, Bent-over Row, Dead lift, Bench Press, Heel Raise
Week			
1	Light	Light	Light
2	Light	Light	Light
3	Moderate	Light	Heavy
4	Heavy	Moderate	Light
5	Light	Heavy	Moderate
6	Moderate	Light	Heavy
7	Heavy	Moderate	Light
8	Light	Heavy	Moderate
9	Moderate	Light	Heavy
10	Heavy	Moderate	Light
11	Light	Heavy	Moderate
12	Moderate	Light	Heavy

Sprint Resistance Exercise – session detail

Weeks 1-6			
	Light	Moderate	Heavy
	3	3	3
Reps	12	8	5
Rest (sec)	90	120	120
Total time (min)	35	40	40

Weeks 7-12			
	Light	Moderate	Heavy
Sets	3	3	3
Reps	10	6	3
Rest (sec)	90	150	180
Total time (min)	35	60	40

Exercise Logs

- **Complete in-flight exercise logs outlining the exercise performed**
  - Aerobic
  - Treadmill & cycle speed, load, duration, HR
  - Resistance
    - Exercise, load, reps, sets & rest between sets

In-flight data collection

- Muscle strength
  - Monitor training loads and adjust prescription as needed
- VO_2max every 30 days
- Muscle size with ultrasound every 30 days

- Prescription can be adjusted accordingly based on in-flight measurements

Pre and post-flight data collection

- Muscle
  - Muscle Function
  - Imaging
  - Muscle Biopsy
- Cardiovascular
  - Pre-, in-, post-flight VO_2max
  - Ventilatory threshold
  - Cardiac ultrasound
- Bone
  - DEXA, qCT

Testing – Muscle Function

- **Leg Press**
  - **Maximal Isometric Force**: Push against fixed footplate.
  - **Power/Endurance**: Push weight away as fast as possible (40% max. force, 21 repetitions). Leg extension push only; weight caught by a braking system.
- **Knee Extension**
  - **Force Control**: Match leg force with a reference force displayed on a computer screen during isometric leg extension (5% maximal force).
  - **Neuromuscular Drive**: Brief, electrical muscle stimulus provided to thigh muscle during isometric leg extension.

- **Bench Press**
  - **Maximal Isometric Force**: Push against fixed bar.
  - **Power/Endurance*:*** Push weight away as fast as possible (30% max force, 21 repetitions) Arm extension only; weight caught by a braking system.
  - **Muscle Force Control*:*** Match isometric arm force with a reference force displayed on a computer screen (5% maximal force).

Testing – mods to standard medical

- Cycle Test MEDB 4.1

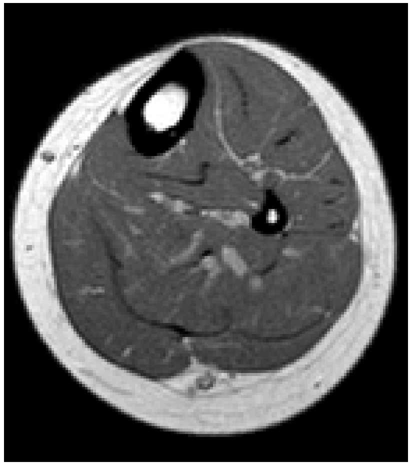
- VO_2max test for ventilatory threshold (L-270, L-80, L-50; R+1-3, 8-10, 30)
  - Peak: 3 min warmup, then 1 min 25 W increments to max
  - Allows for evaluation of ventilatory threshold which has never before been assessed with spaceflight but is more functionally important than VO_2max

Bone – density and architecture

- **Bone densitometry MEDB 1.11**
  - DEXA scan, L-<365, R+30, R+180, then yearly
- **Add qCT for bone density and geometry of hip and spine**
  - L-<365 and R+30

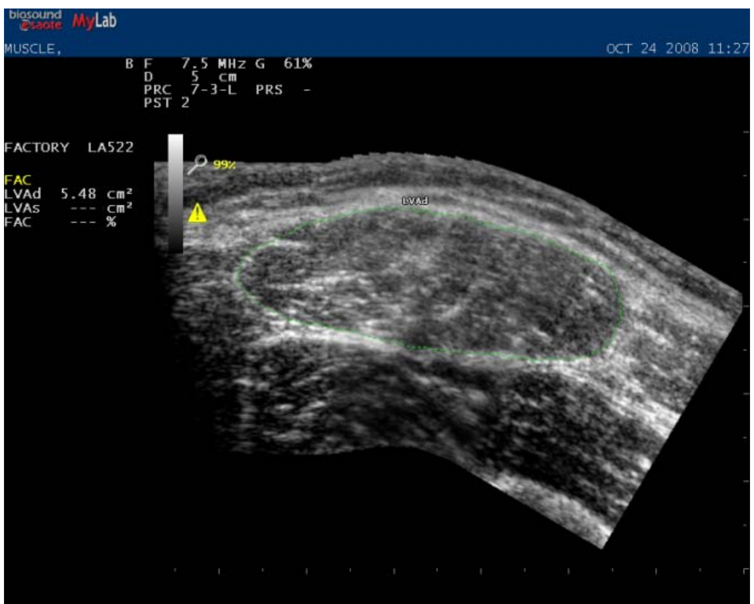
Imaging- MRI for muscle size

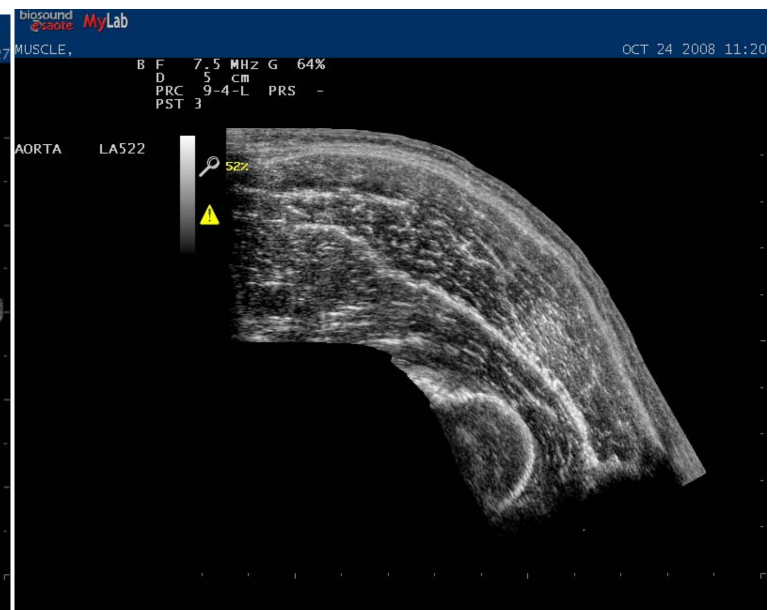
- MRI of the legs for muscle size/volume of thigh and calf (L-80, L-50; R+ 1-3)
  - 30 min supine rest
  - 8 min scan of calf
  - 8 min scan of thigh



Imaging- Ultrasound

- Ultrasound of the leg muscles (L-80, 50; R+0-1)
- Cardiac ultrasound





Pre-flight	Post-flight
L<365: DXA*, QCT†	R+0/1: Ultrasound, Muscle Biopsy
L-270: Peak Cycle (VO2max)*	R+1: Muscle Performance†, MRI, VO2max**
L-180: Isokinetic Testing*, Muscle Performance†	R+5-7: Isokinetic Testing*
L-80: Isokinetic Testing*, Muscle Performance†, MRI, Ultrasound, VO2max**	R+6: Muscle Performance†
L-50 (as close to departure as possible): Isokinetic Testing, Muscle Performance†, MRI, Ultrasound, VO2max	R+8-10: VO2max†
L-45: Muscle Biopsy (optional)	R+30: Isokinetic Testing*, Muscle Performance†, VO2max**
	<R+30: DXA*, QCT†
6.25 hrs shared medical 10 hrs study specific and possible experiment data sharing	**6 hrs shared medical 6.5 hrs study specific and possible experiment data sharing**

* Nominal Medical testing requirement

** Testing replaces existing nominal medical testing requirement (either Functional Fit or Submax)

† Possible Data Share with existing experiments

Inflight Medical Requirements/Activities	**Inflight Sprint**
Periodic Fitness Evaluation (PFE): • FD 14 and about every 30 days after (6 sessions/1.5 hrs per session) • 9 hrs total	VO2max (replaces PFE): • FD 14 and about every 30 days after (6 sessions/3.6 hrs per session) • 21.5 hrs total
	Muscle ultrasound: • FD 14, 30 and about every 30 days after (7 sessions/1.75 hrs per session) • 12.25 hrs total
Throughout mission: • 2.5 hrs per day of exercise training	Throughout mission: • 15-90 min per day of exercise training*
Total testing time (PFE) = 9 hrs	**Total testing time = 33.75 hrs**

*2.5 hrs of exercise time will still be scheduled daily

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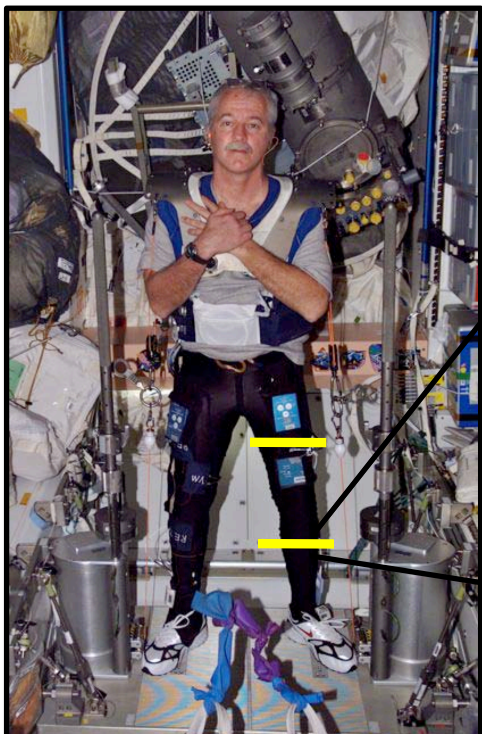
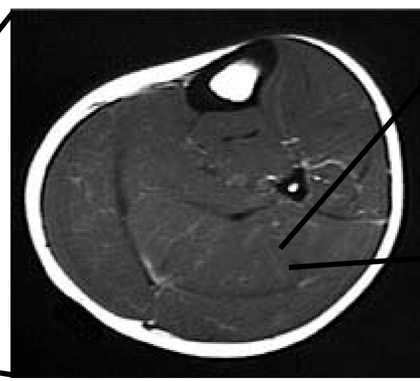
Muscle Biopsy

Whole Muscle → Cellular Level

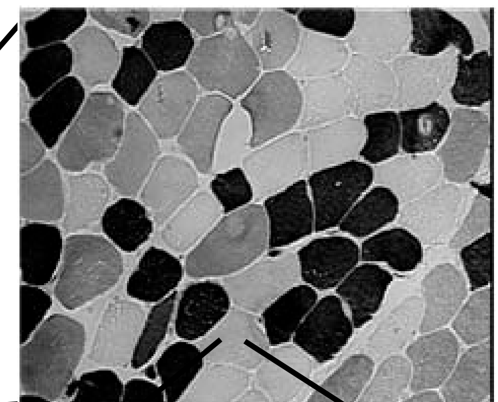


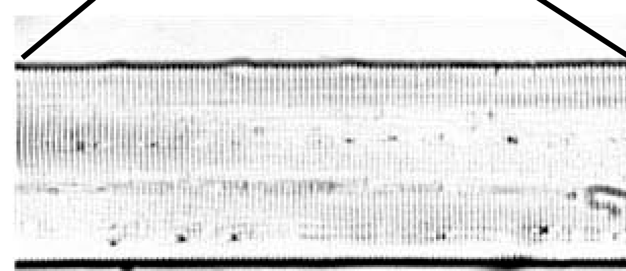
Exercise on the ISS



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

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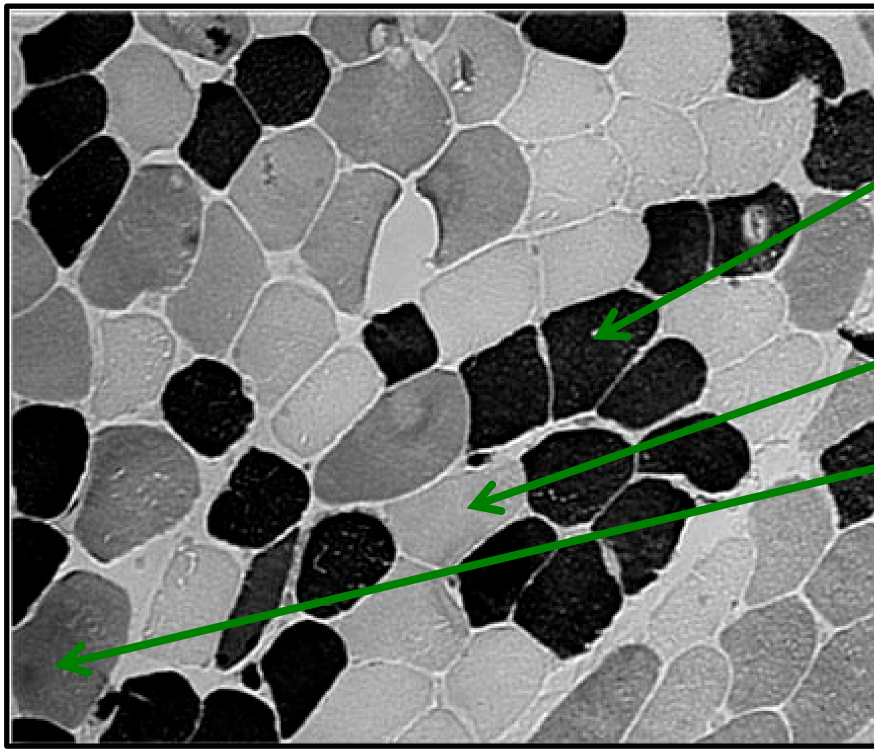
Muscle Biopsy



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

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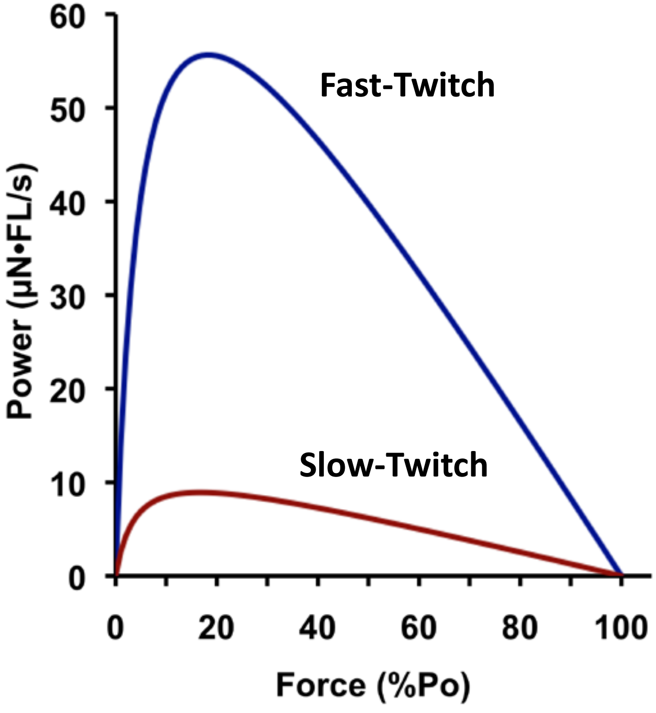
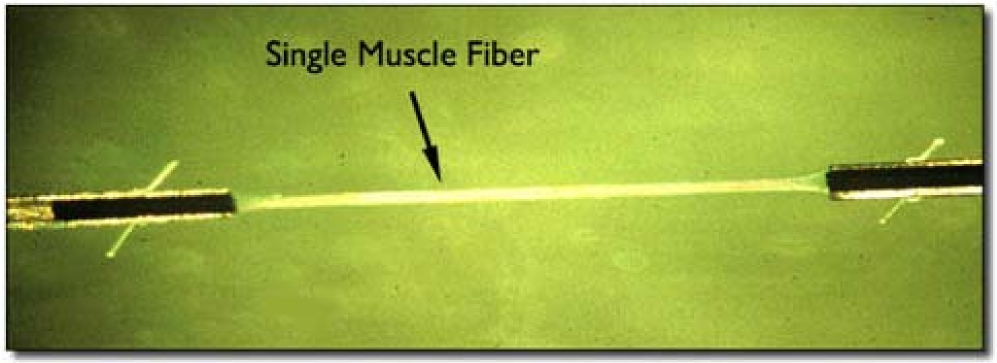
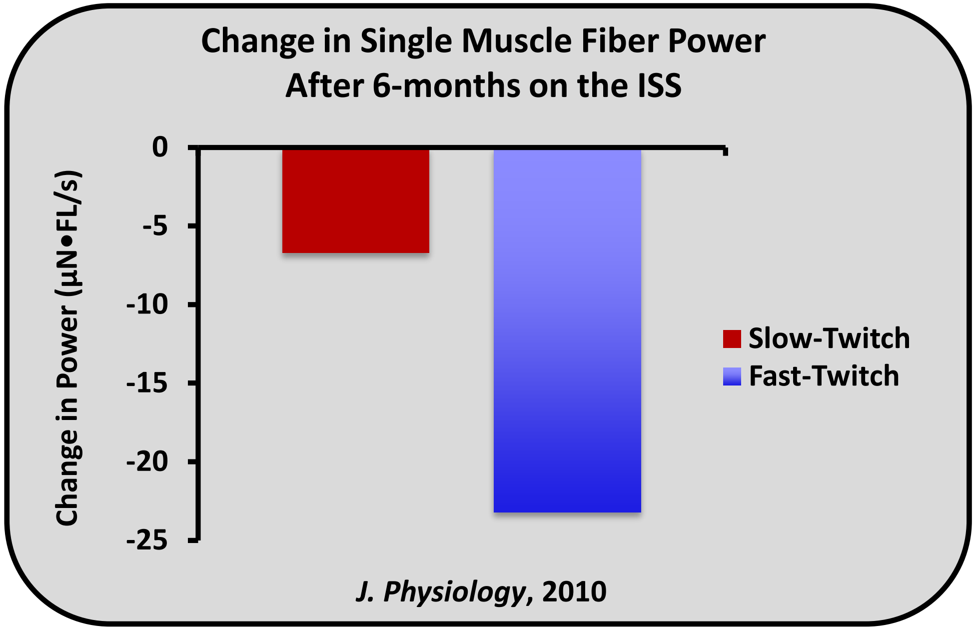
Muscle Biopsy

Single Muscle Fiber Power







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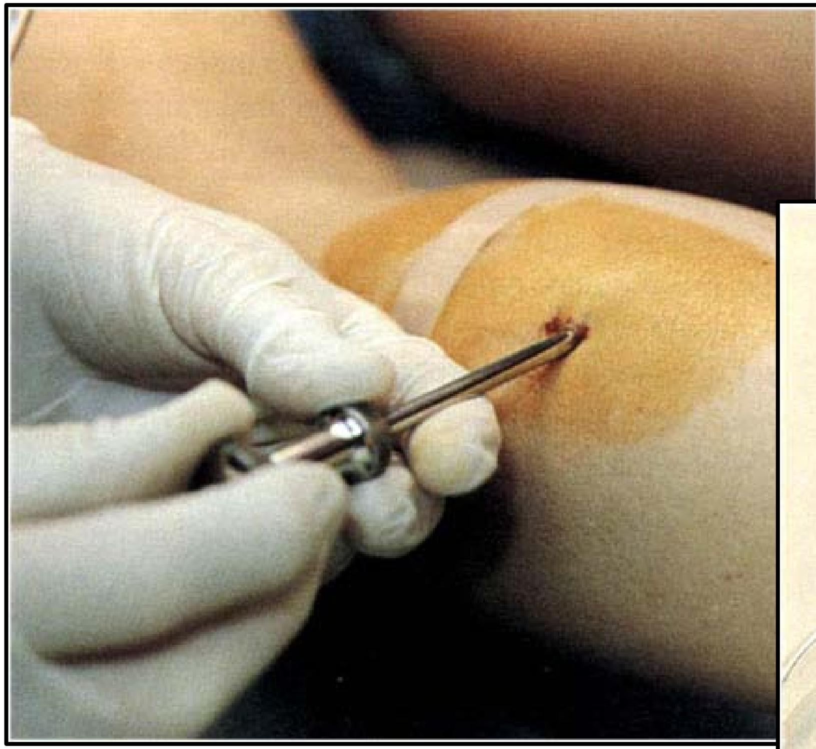
Muscle Biopsy

Pre: L-50-55
Post: R+0



Calf – Soleus
Thigh – Vastus Lateralis

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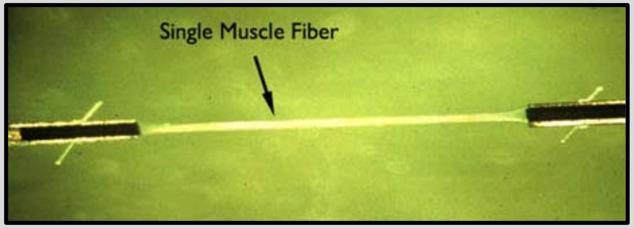
Muscle Biopsy – Science

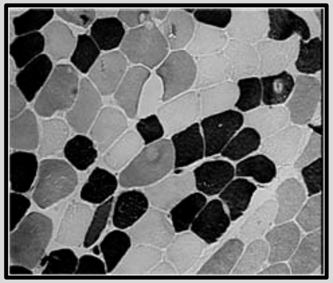
Function & Structure

1. Single Muscle Fiber Function



To determine size, strength, speed and power in slow-and fast-twitch muscle fibers which impacts muscle performance

2. Muscle Fiber Type Transformations



To determine changes in fiber type which impacts muscle performance, metabolic health, fuel use, and fatigue

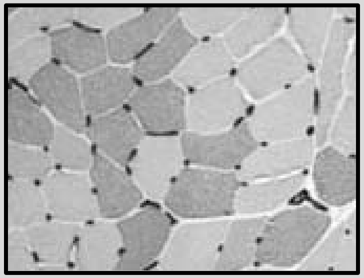
Metabolic Capacity

3. Aerobic and Anaerobic Enzymes

Mitochondria

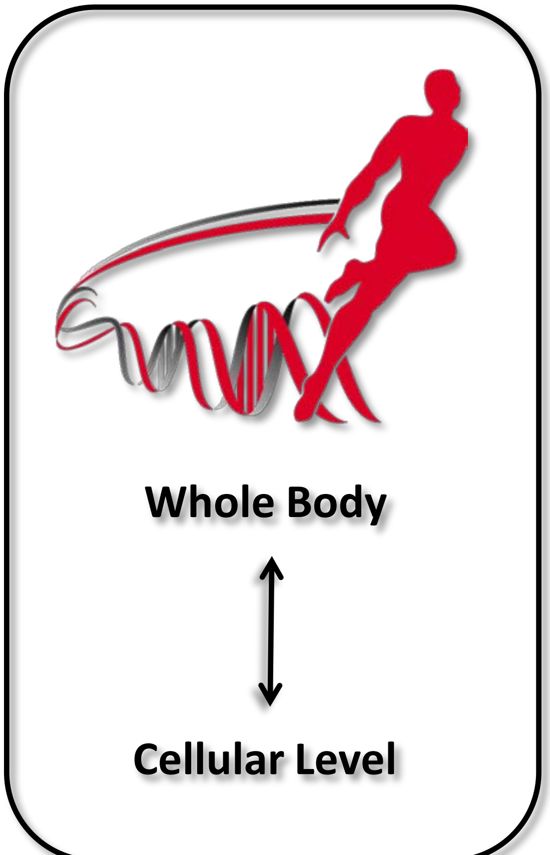
Muscle Biochemistry to determine metabolic profile which impacts energy transfer and metabolic health

4. Capillary Density



To determine capillary network which impacts blood flow, oxygen, and nutrition delivery

Muscle Biopsy – Science Application



1. The cellular data will complement the whole muscle assessment to provide a detailed profile of skeletal muscle health and the effectiveness of the current ISS hardware and new exercise prescription.

2. Our recently published ISS muscle biopsy research from Increment 5-11 in combination with new whole muscle and cellular information will provide a strong scientific platform to help guide future countermeasure programs.

Recent ISS muscle publications: 1. Trappe et al. *JAP* 106: 1159-68, 2009 and 2. Fitts et al. *J. Physiol*. 2010.

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Muscle Biopsy Team Experience

R+0 biopsy in Star City

Space Flight: Shuttle & ISS
14 crewmembers
56 muscle biopsies total

Bed Rest: 17, 60 and 90-d

Aging: up to 93 years old

Athletes: Recreational, Competitive, and Olympic

Drs. Scott and Todd Trappe have performed >3,000 muscle biopsies (Human Performance Laboratory > 10,000)

Experiment Training

- **L-18-12 months**
  - 1 hr overview familiarization
- **L-12-6 months**
  - 2 hr PPFS
  - 1.5 hrs VO2max nominal operations
  - 1 hr ultrasound
- **L-18 months (as soon after consent as possible)**
  - Sprint exercises during scheduled gym time

Possible Risks or Discomforts

- Reasonable risk
- Imaging
  - MRI – personal injury from magnetic objects, noise, claustrophobia
  - qCT – radiation exposure
  - Ultrasound – gel
  - Protections – screen for metal implants, earplugs, feet first scanning, monitor crew radiation exposure, ask about allergy to ultrasound gel.
- Muscle biopsy
  - Discomfort, bleeding, infection, scarring of skin
- Protections – use of standard sterile procedures, experienced investigator to obtain biopsy.

Possible Risks or Discomforts

- Exercise testing – typical risks associated with exercise
  - Muscle soreness, cramping, joint injury, strains, sprains, cardiovascular events, light-headedness after exercise, discomfort
  - Protections – warm up, supervision, concentric only contractions, subjects already screened for heart disease, cool down

Participation Options

- Active subject - Full participation of all pre-, in-, and post-flight data collection and in-flight exercise program
- Control subject - Pre- and post-flight testing only
- Muscle biopsy