NASA Spine Workshop
25-26 Jan 2018

Derek M. Nusbaum, MD, PhD

ISS Exp 59/60 Deputy Crew Surgeon

Richard A. Scheuring, DO, MS, RMSK, FAsMA
Team Lead, Musculoskeletal Medicine and Rehabilitation
ISS Exp 52/53 Crew Surgeon

SD3/R. Scheuring 3-9769

Acknowledgments

– EMR: T. Bradley, M. Hughes
– LSAH: M. Laughlin, J. Murray, M. Van Baalen
– ASCRs: B. Nieschwitz, M. Guilliams, S. Latham
– Astronaut office: K. Rubins, J. Williams, T. Marshburn, K. Lindgren, D. Morgan, R. Bresnik
– Bone lab: J. Sibonga
– Muscle lab/Exercise lab: M. Downs, J. DeWitt, L. Goetchius, B. Cromwell
– FMC: L. Smith, R. Shah
– SD Mgmt: R. Reed, S. Moynihan
– NASA Flight Surgeons

Day 1 Agenda

0800-0830	Welcome and Introduction
0830-0900	Background, goals and objectives
0900-1030	Case reports of lumbar spine pain in the US astronauts
1030-1035	Break
1040-1110	Back Pain Epidemiology in active US astronaut corps
1110-1140	Review of the current pre-, in- and post-flight astronaut conditioning program
1200-1300	Working lunch: Review of intervertebral disc research results in US astronauts
1315-1415	Evaluate current pre-, in-, and post-flight injury prevention and treatment strategies among U.S. astronauts
1415-1445	Best practices for back rehab in terrestrial populations
1500-1520	Future in-flight exercise devices
1520-1620	Discussion and recommendations
1630-1700	Recommendations summary

Day 2 Agenda

0800-0900	Background and summary of recommendations from Day 1 and short Intro from Alan Hargens
0900-0940	Update on IVD cervical work
0940-1020	Overview of in-flight IVD ultrasound study
1020-1100	Overview of in-flight spinal lengthening study
1100-1130	Assessing/Screening muscle function- Russian experience
1130-1200	Role of the vertebral endplate in LBP and spine disorder
1200-1300	Break for lunch
1300-1500	Future directions and countermeasures for spine

- Come up with list of countermeasures and screening measurements
- Discussion about value of a possible in-flight muscle ultrasound study
- Develop a workshop summary for supporting a study for future validation studies
- Pre-flight paraspinal muscle training guidelines

Participants

Subject Matter Experts
- J. Bob Blacklock, MD- Neurosurgery Houston Methodist
- Paul Holman, MD- Neurosurgery, Houston Methodist
- John Cianca, MD- PM&R Memorial Hermann Houston
- Benoy Benny, MD- PM&R The Spine and Sports Medicine Center Houston
- Hani Kaykal, MD- Neuroradiology Houston Methodist
- Roy Riascos-Casteneda, MD- Neuroradiology UT Medical Center
- Ron Alkalay, PhD- VEP/IVD Physiology Harvard Beth Israel Boston
- Chris Gilligan, MD- Pain Harvard Beth Israel
- Vijay Jotwani, MD- Primary Care Sports Medicine Houston Methodist
- Danny Keller, PT, DPT, MFDc USCF
- Kenny Leung, PT, DPT, MFDc UCSF
- Mark Guilliams, MS, ASCR NASA Johnson Space Center
- Bruce Neischwitz, MS, ASCR NASA Johnson Space Center
- Joel Dixon, DPT, ATC, LTC USAF- US Air Force Academy
- Eric Wilson, DPT, MAJ, USAF- US Air Force Academy

- **UCSD/SF IVD Project Team**
- Alan Hargens, PhD
- Jeff Lotz, PhD
- Doug Chang, MD, PhD
- Jeannie Bailey, PhD
- Dezba Coughlin, PhD
- JoJo Sayson, PT, DC
- Robert Healey, MS

NASA Flight Surgeons
- David Alexander, MD, MPH
- James Pattarin, MD, MPH
- Derek Nusbaum, MD, PhD
- Joe Dervay, MD, MPH
- Kathleen McMonigal, MD
- Steven Piper, DO
- Eric Kerstman, MD
- Steve Hart, MD
- Robert Mulcahey, MD, MPH
- Ronak Shah, DO, MPH
- Ben Johansen, DO, MPH
- Rick Scheuring, DO, MS

NASA Astronauts
- Jeff Williams, COL (ret.) USA
- Kate Rubins, PhD
- Kjell Lindgren, MD, MPH
- Randy Presnik, COL (ret.) USMC
- Drew Morgan, MD, LTC USA
- Jonathan Kim, MD, MAJ USN
- Frank Rubio, MD, MAJ USA

Russian Cosmonaut and Flight Surgeon
- Oleg Kotov, MD
- Ilya Rukavnishkov, MD

Background

NASA MSK Summit 2005

Microgravity associated lumbar spine pain in astronauts

NASA IVD Damage Summit 2009

IVD damage following space flight is evident in astronauts but the relationship btw microgravity and spinal changes leading to pain is not clear

NASA Low Back Pain Meeting 2015

Evaluation of lumbar spine pain

Event	Number of Events	Incidence/100 Days
Musculoskeletal	7	0.74
Skin	6	0.63
Nasal congestion, irritation	4	0.42
Bruise	2	0.21
Eyes	2	0.21
Gastrointestinal	2	0.21
Psychiatric	2	0.21
Hemorrhoids	1	0.11
Headaches	1	0.11
Sleep disorders	1	0.11

NOTE: Data from the Russian Space Agency reports that there were 304 in-flight medical events onboard the *Mir* from February 7, 1987, through February 28, 1998. The numbers of astronauts at risk or the incidence per 100 days was not reported.

SOURCE: Marshburn, 2000b.

Objectives

1. What medical surveillance studies might be beneficial given the prevalence of the problem and constraints of crew time?
2. What countermeasures, not already used, might be implemented to mitigate those factors contributing to back pain in astronauts pre-, in- and post-flight?
3. What role might pre-existing lumbar spine disease play in the etiology of in- and post-flight pain?
4. What activities, exercises, or other rehabilitation adjuncts can we apply in- and post-flight to mitigate lumbar spine pain in those individuals with known DDD?
5. Thoughts on what long-term complications there may be years after spaceflight exposure?
6. Given the known spinal changes, provide considerations for future space flight exercise devices.

Epidemiology

- To perform an evaluation of reported post-flight back pain cases and relevant spaceflight risk factors in US ISS astronauts
- Data since the 2015 summit was added and additional risk factors investigated

Spaceflight Related Risk Factors

- Age
- Sex
- Genetics
- Prior history of back pain or injury
- Occupational hazards – prior military service
- Exercise countermeasures
- Axial-loading immediately post-flight

Case Definition

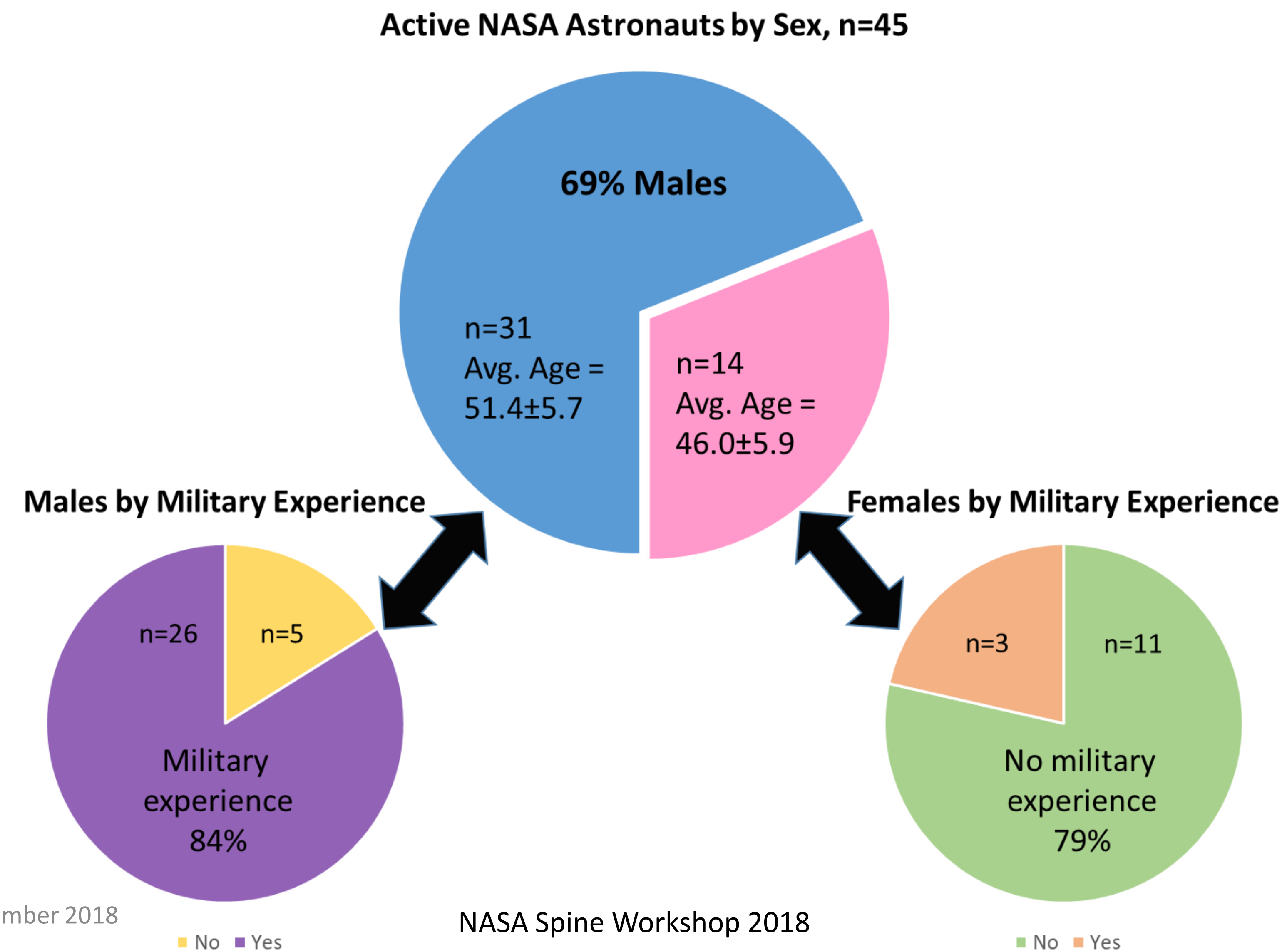
- A case was defined as a reported event of back pain or injury to the cervical, thoracic, lumbar, sacral or coccyx spine regions.
- Pre-flight case within L-6months, L-3years, and any pre-flight report
- Post-flight case before R+45 and R+1year

- Data sources
  - EMR
  - Astronaut Strength, Conditioning and Rehabilitation
  - Private Medical Conferences tool
  - Space Medicine Operations Team

ISS Expeditions 1-51

- US Crewmembers
  - 40 Male astronauts (4 have stayed on ISS twice, 1 has stayed on ISS three times)
  - 10 Female astronauts (1 has stayed on ISS twice, 1 has stayed on ISS three times)
  - Average age: 47.5 years
  - Average length of mission: 169 days
    - 341 days (longest) to 58 days (shortest)
- Individuals not included in this presentation
  - Russian Cosmonauts
  - International Partner Astronauts (ESA, CSA, and JAXA)

NASA Astronauts by Sex and Military Experience



Number of Cases

- Anytime prior to launch – 34 (58%)
- L-3years to launch – 16 (27%)
- L-6months to launch – 6 (10%)

- Landing to R+45days – 15 (25%)
- Landing to R+1year – 21 (36%)

Reports of Spine Pain by Region in ISS astronauts

	Pre-flight	In-flight	Post-flight
Unknown	5	11	1
Cervical	14	2	13
Thoracic	5	1	6
Lumbar	31	13	29
Sacrum	1	0	7
Coccyx	1	0	1
Total	**57**	**27**	**57**

*Denominator is 50 US ISS astronauts

Multivariate Analyses

- Age
- Sex
- Occupational Hazard
- Prior History (L-180d, L-3y or L-Any)
- Exercise Countermeasures
- Research Participation

- No single variable significantly predicts post-flight pain or injury.
- Only ~20% of the variance is accounted for, so other factors account for 80% of variance in post-flight cases.

Conclusions

- Regardless of cause – post-flight back pain & injuries are reported more often since ARED was deployed and FTT type studies began
- No single spaceflight risk factor explains the data – 80% of variance is unaccounted for
- Likely multi-faceted factors resulting in post-flight back pain and injury cases

Current annual screening for spinal disorders for US astronauts

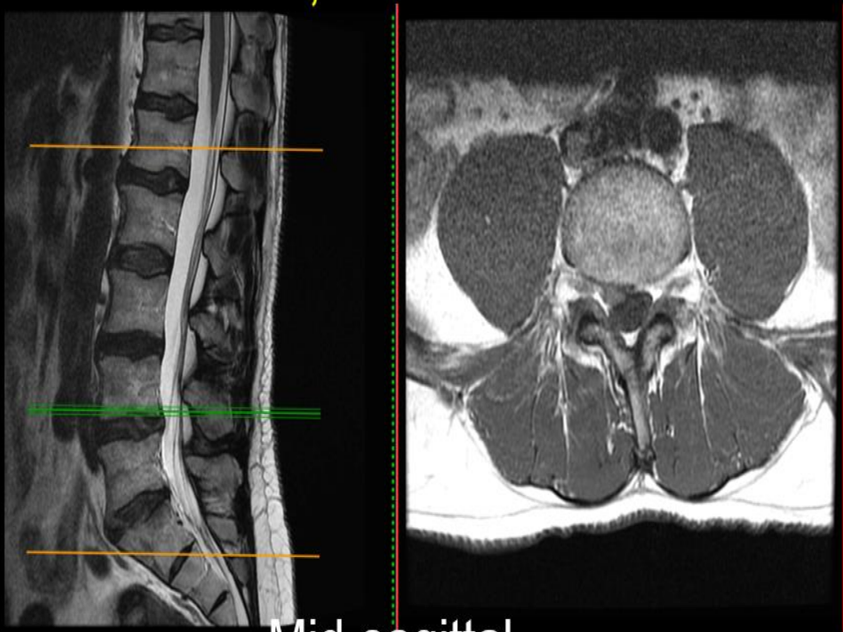
- Annual flight physical
- Further investigation into spine health depends on presenting symptoms to the flight surgeon
- DXA BMD is performed as follows:
  - L- 21/18 months (w/AME) 60 min
  - L- 180/30 d (as close to launch as possible) 60 min
  - R+ 5/30d 60 min
  - then as clinically indicated to assess BMD recovery
- Plain radiographs or MRI/US **are not** routinely performed on astronaut selectees or US astronauts unless clinically indicated

Case Reports (12)

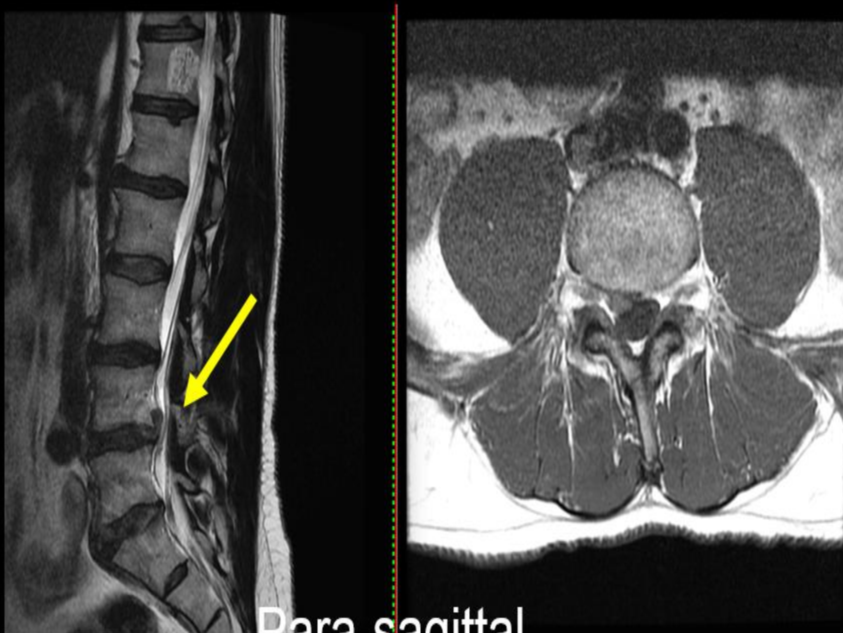
- A select number of astronaut lumbar spine pain/injury cases are presented, and are generally representative of all cases seen at NASA over 50 yrs
- Pre-NASA occupational hx, BMDs, Radiation exposure, and relevant imaging will be discussed
- All laboratory values and body mass composition are considered WNLs unless otherwise noted
- Non-MSK related medications (e.g. anti-HTN, statins, thyroid) are not listed
- All in-flight reports were conducted during the Private Medical Conference (PMCs)
- 25-OH Vit D, ESR, TFTs, LFTs, CBC w/diff, CRP, testosterone, Intact PTH, Ionized Ca, Osteocalcin, Alk Phos, N-Telopep, C-Telopep otherwise unremarkable
- Lumbar spine imaging studies are not performed at astronaut selection or pre-mission assignment unless clinically indicated
- Pain ≠ injury
- A number of astronauts have had cervical spine issues during their career
- Aside from clarifications on data or time course, let's hold questions until the end of the case presentations

006

2014, clinical MRI



Mid-sagittal



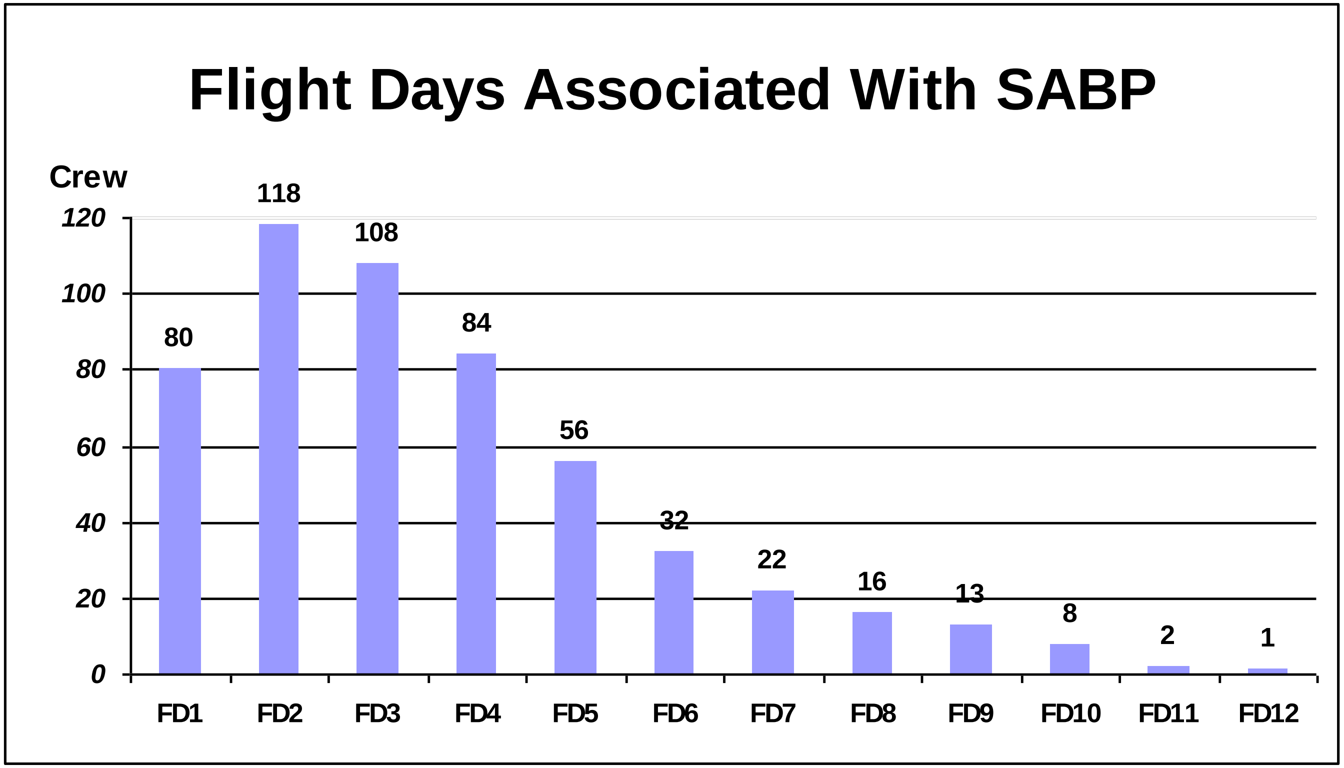
Para-sagittal

2016, clinical MRI

(L4-L5 herniation resorbed)

SABP & Flight Days

SABP is present in the early phase of spaceflight, with a peak prevalence on flight day 2 and none reported after flight day 12

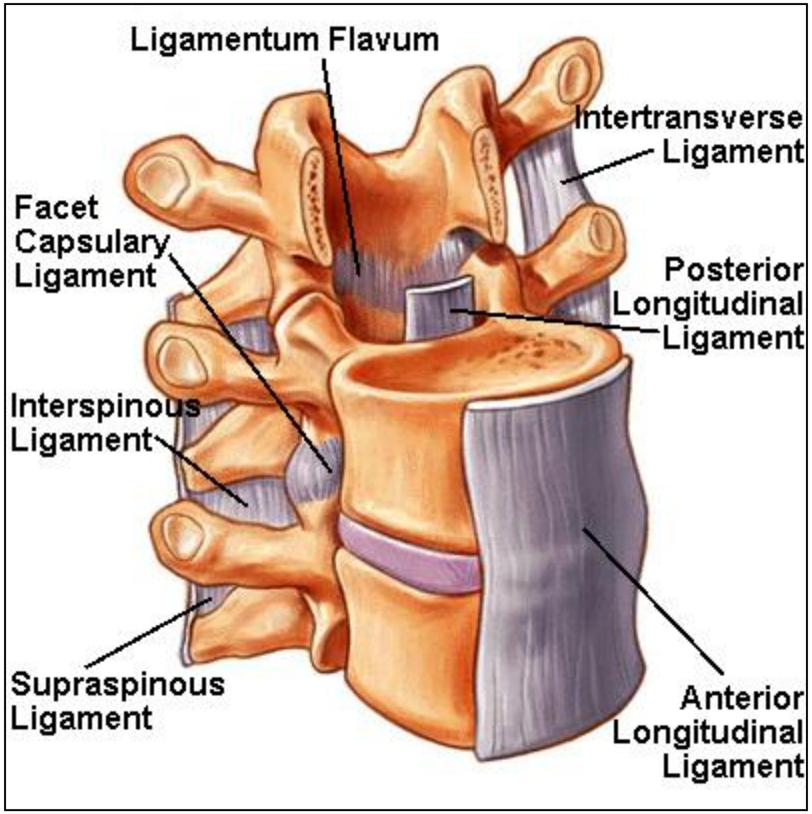


Results

- The incidence of SABP has been determined to be 53-68% among astronauts in the U.S. space program
- Most cases of SABP are mild, self-limited, or respond to available treatments
- There are no currently accepted preventive measures for SABP
- It is difficult to predict who will develop SABP
- The precise mechanism and spinal structures responsible for SABP are uncertain
- There was no documented evidence of direct operational mission impact related to SABP
- There is ***potential*** mission impact related to uncontrolled pain, sleep disturbance, or the adverse side effects of anti-inflammatory medications

Etiology of In-flight back pain

- IVD/VEP changes
- Thoracolumbar myofascial changes
- Facet arthrosis
- Stretching/atrophy of the spinal stabilizers, anterior longitudinal ligament, or tearing of the annulus fibrosis
- Preexisting lumbar DDD



In-flight Treatment of SABP

Nada Chair by Nada-Concepts, Inc.

In-Flight Musculoskeletal Injuries

RESEARCH ARTICLE

Musculoskeletal Injuries and Minor Trauma in Space: Incidence and Injury Mechanisms in U.S. Astronauts

Richard A. Scheuring, Charles H. Mathers, Jeffrey A. Jones, and Mary L. Wear

Scheuring RA, Mathers CH, Jones JA, wear ML. *Musculoskeletal injuries and minor trauma in space: incidence and injury mechanisms in U.S. astronauts.* **Aviat Space Environ Med 2009; 80:117–24.**

Introduction: Astronauts have sustained musculoskeletal injuries and minor trauma in space, but our knowledge of these injuries is based mainly on anecdotal reports. The purpose of our study was to catalog and analyze all in-flight musculoskeletal injuries occurring throughout the U.S. space program to date. ***Methods:*** A database on in-flight musculoskeletal injuries among U.S. astronauts was generated from records at the Johnson Space Center. ***Results:*** A total of 219 in-flight musculoskeletal injuries were identified, 198 occurring in men and 21 in women. Incidence over the course of the space program was 0.021 per flight day for men and 0.015 for women. Hand injuries represented the most common location of injuries, with abrasions and small lacerations representing common manifestations of these injuries. Crew activity in the spacecraft cabin such as translating between modules, aerobic and resistive exercise, and injuries caused by the extravehicular activity (EVA) suit components were the leading causes of musculoskeletal injuries. Exercise-related injuries accounted for an incidence of 0.003 per day and exercise is the most frequent source of injuries in astronauts living aboard the International Space Station (ISS). Interaction with EVA suit components accounted for an incidence of 0.26 injuries per EVA. ***Discussion:*** Hand injuries were among the most common events occurring in U.S. astronauts during spaceflight. Identifying the incidence and mechanism of in-flight injuries will allow flight surgeons to quantify the amount of medical supplies needed in the design of next-generation spacecraft. Engineers can use in-flight injury data to further refine the EVA suit and vehicle components.

Keywords: astronaut, NASA, strain, sprain, abrasion, contusion, laceration, dislocation, EVA, injury.

NASA ASTRONAUTS face a variety of occupational hazards throughout their career. In addition to the risks inherent to space travel, astronauts perform physically demanding tasks in unfamiliar environments. Coupled with bone and muscle mass loss due to the effects of microgravity on the human body, one could hypothesize that astronauts may be at increased risk for sustaining musculoskeletal injuries while conducting space operations. Indeed, anecdotal reports from astronauts and postflight mission debriefings in all NASA spaceflight programs support this theory, as many astronauts have noted in-flight musculoskeletal injuries. However, until recently, our understanding of these injuries was based primarily on anecdotal reports, without evidence-based data to support these claims.

Jennings and Bagian conducted a study examining the terrestrial-based orthopedic injury history of astronauts during the period of 1987 to 1995 (5). The authors found astronauts sustained numerous fractures, serious ligament, cartilage, or soft tissue injuries, resulting in 28 orthopedic surgical procedures during this period. Knee injuries accounted for 19 of the surgical interventions, while running, skiing, and basketball were the activities most frequently associated with injuries. The authors recommended the hiring of full-time personal trainers and the designation of a facility for training purposes at Johnson Space Center, both of which are now in place as manifested in the Astronaut Strength, Conditioning, and Rehabilitation (ASCR) program. Jennings and Bagian recognized the importance of understanding the mechanism of injury or trauma, noting that it was "time to move beyond documentation of injuries and treatment to providing a program that strives to prevent or mitigate training-related injuries." This important study is often cited in discussions regarding musculoskeletal injuries and prevention in astronauts, but did not address in-flight occurrences.

An article printed in the Longitudinal Study of Astronaut Health (LSAH) newsletter in December 1999 examined the musculoskeletal injury rates of shuttle astronauts between Shuttle Transport System (STS)-1 and STS-89 (12). The authors found an overall greater in-flight injury rate among astronauts than comparison participants in the LSAH. Interestingly, they also found a threefold higher injury rate within astronauts' mission period, defined as 1 yr preflight to 1 yr postflight, versus the rate outside the mission period. This raised questions as to how much of this increase was attributed to preflight training, postflight injury due to de-conditioning, or in-flight injury.

We know that astronauts sustain injuries during the preflight period, especially during training sessions in

From NASA Johnson Space Center, Houston, TX; The University of Texas Medical Branch, Galveston, TX; and Wyle Laboratories, Houston, TX.

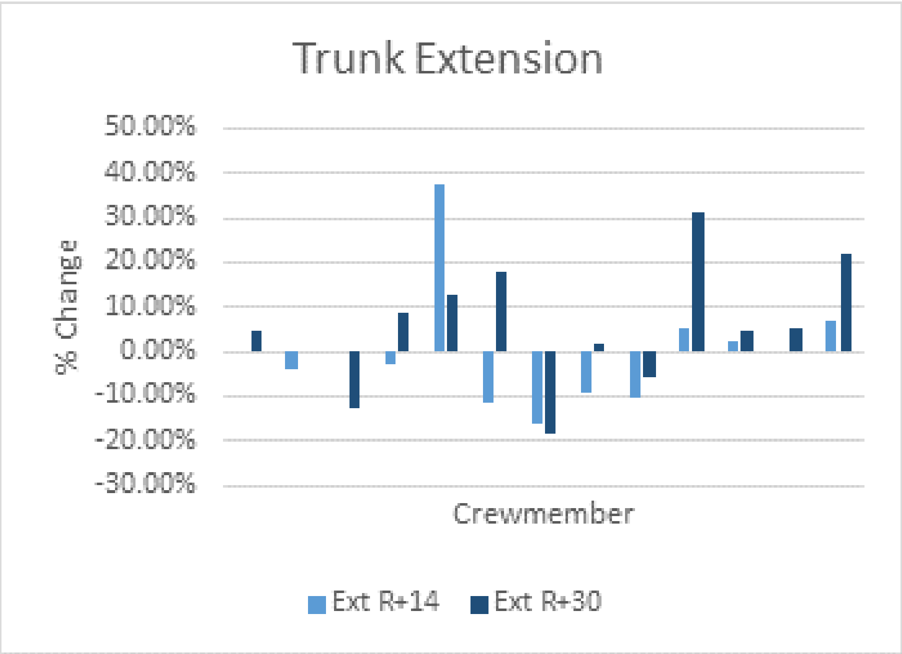
This manuscript was received for review in January 2008. It was accepted for publication in November 2008.

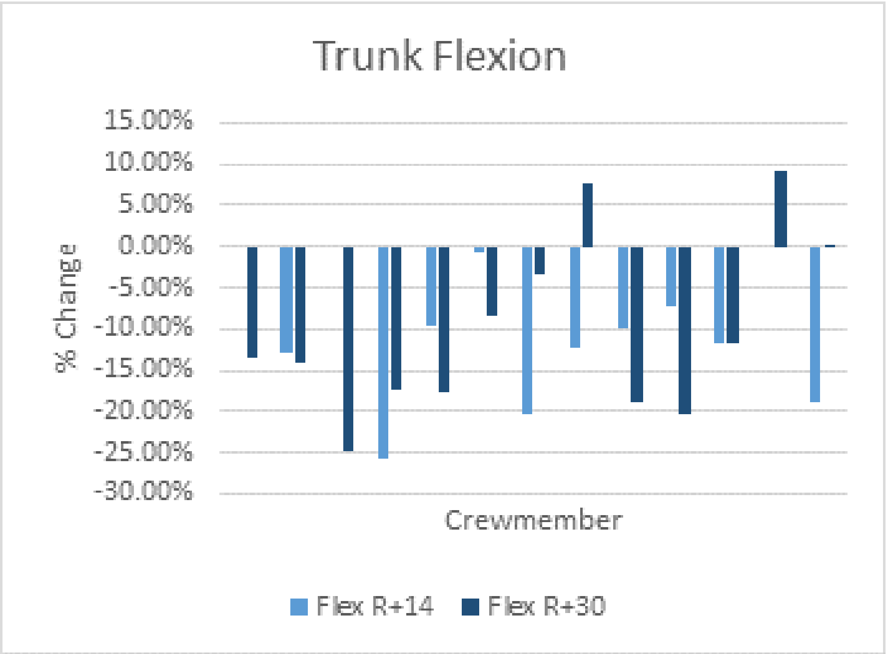
Address reprint requests to: Richard A. Scheuring, D.O., M.S., NASA Johnson Space Center, SD4, 2101 NASA Parkway, Houston, TX 77058; richard.a.scheuring@nasa.gov.

DOI: 10.3357/ASEM.2270.2009

- A total of 369 in-flight musculoskeletal conditions were found, from which 219 in-flight musculoskeletal injuries were identified
  - 21 in women and 198 in men.
  - Incidence over the course of the space program was 0.021 per flight day for men and 0.015 for women.
  - Hand injuries represented the most common location of injuries throughout the U.S. space program, with abrasions and small lacerations representing common manifestations of these injuries.
  - Exercise-related injuries accounted for an incidence rate of 0.003 per day.

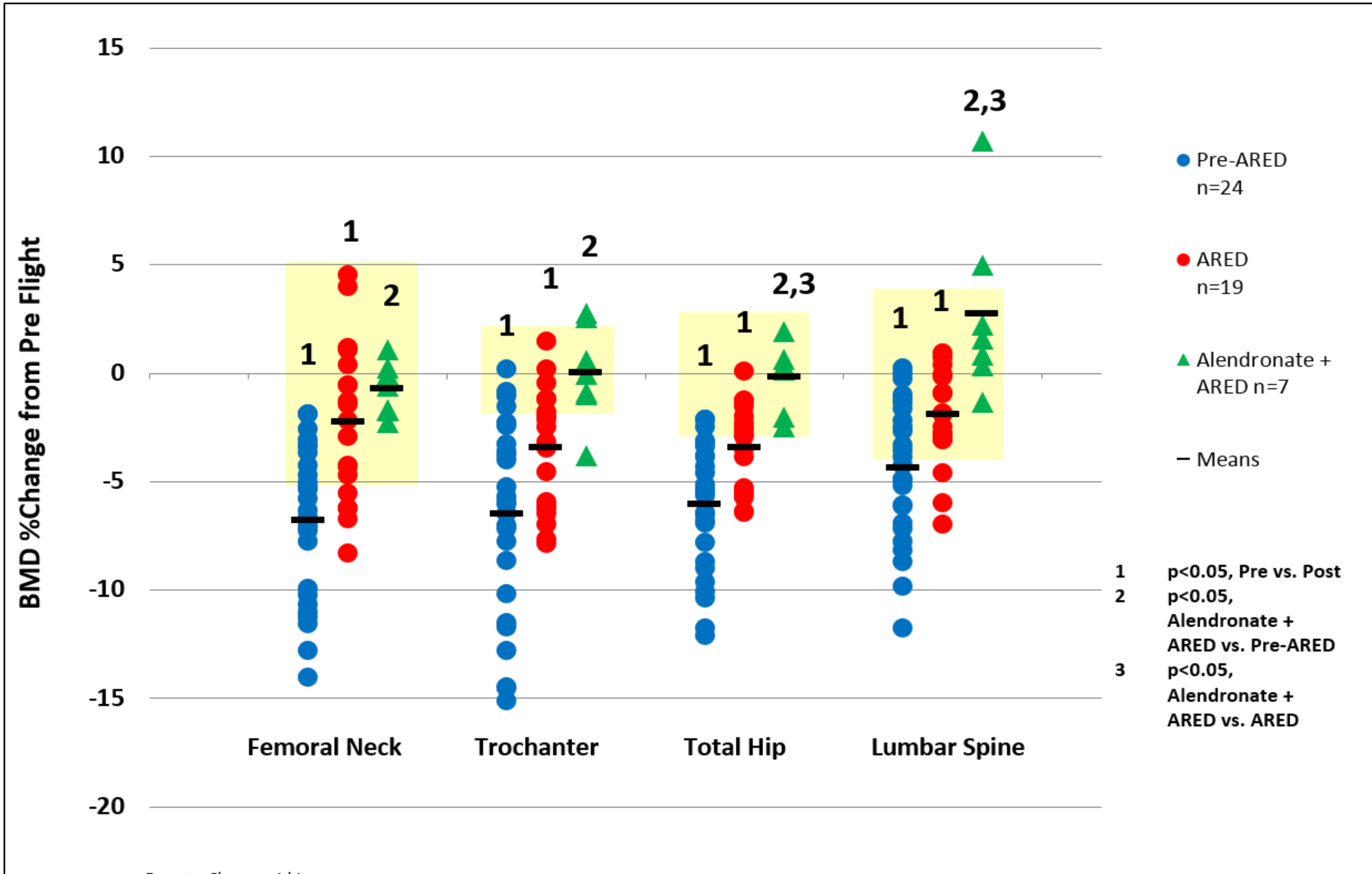
Pre- & Post-flight Isokinetic Strength





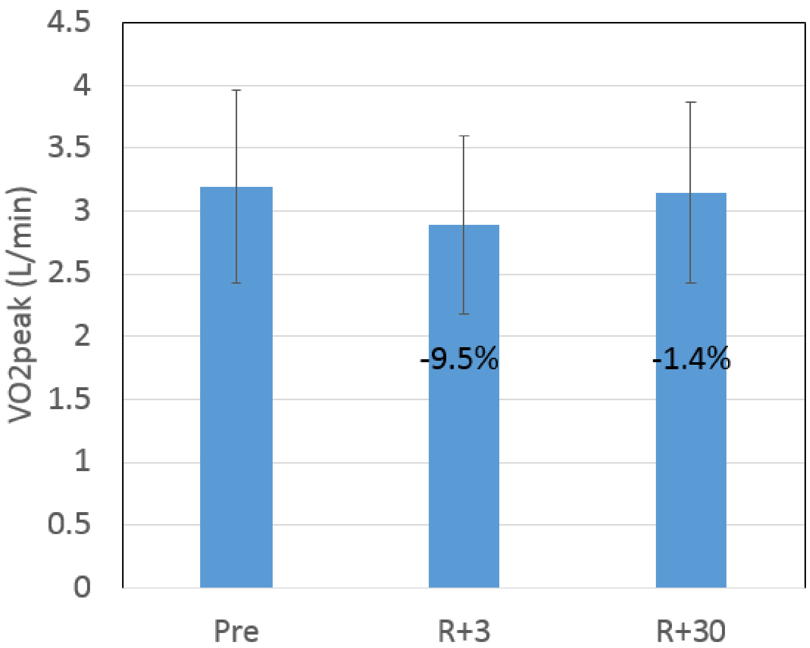
Data courtesy of L. Goetchius

DXA Bone Mineral Density

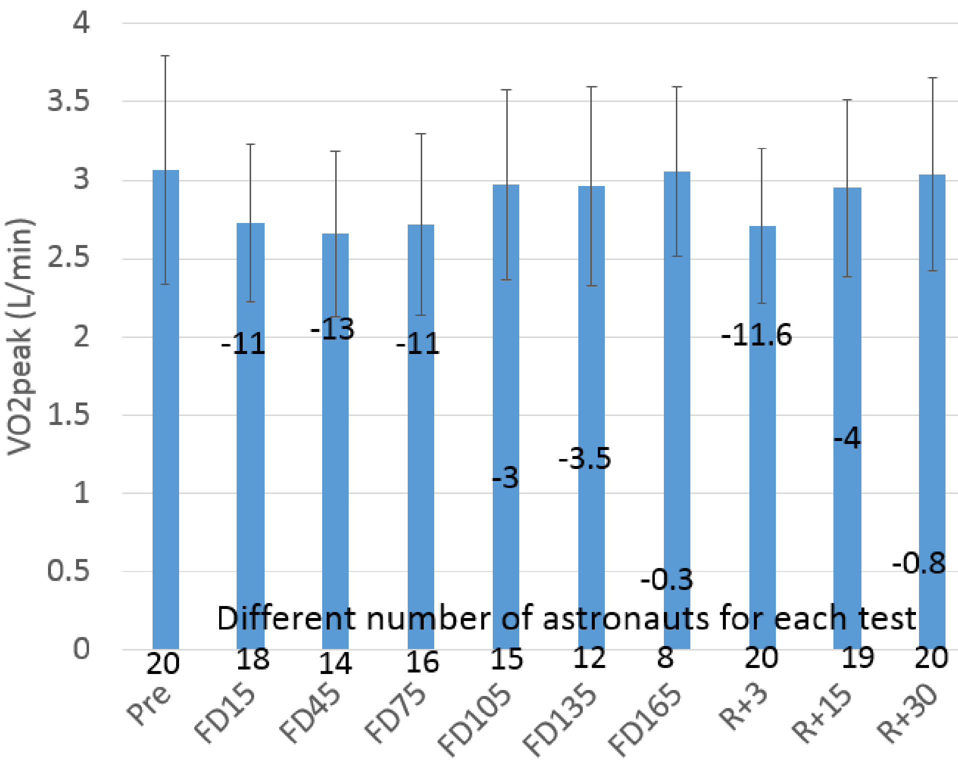


Data courtesy of J. Sibonga, PhD

ISS Astronauts: Pre and Post Flight VO2 Peak



36 astronauts



Data courtesy of M. Downs, PhD

Radiation

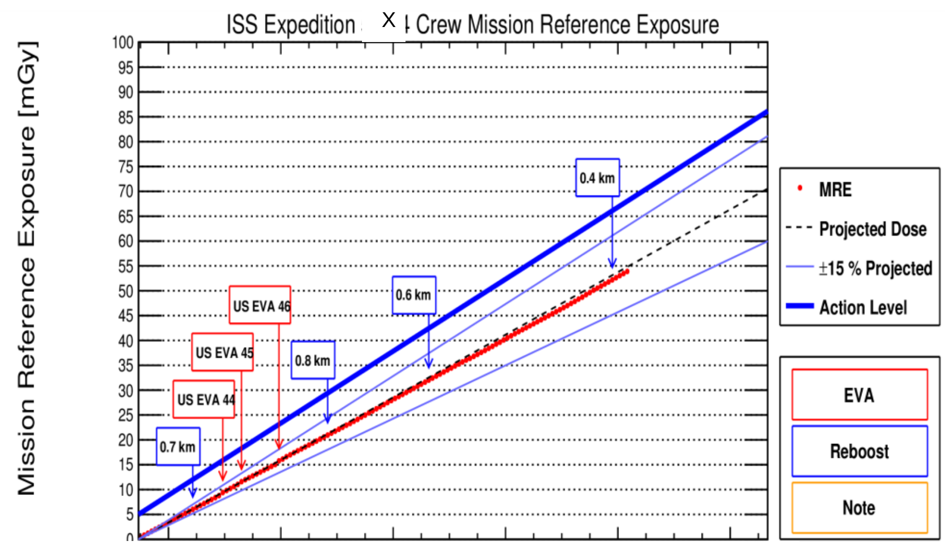
1. Exposure based on orbital altitude/inclination, duration, and solar activity

2. Crewmembers are radiation workers

   Limits for mission and career exposure are set by the National Council on Radiation Protection

3. As Low As Reasonably Achievable (ALARA) principle for mission planning

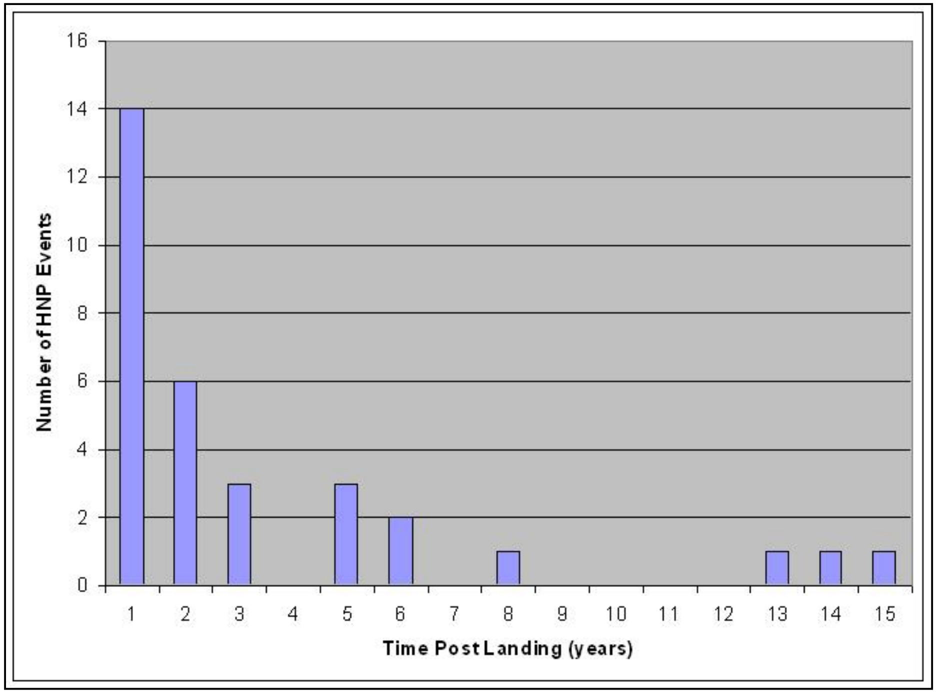
4. Exposure monitored by active and passive dosimeters

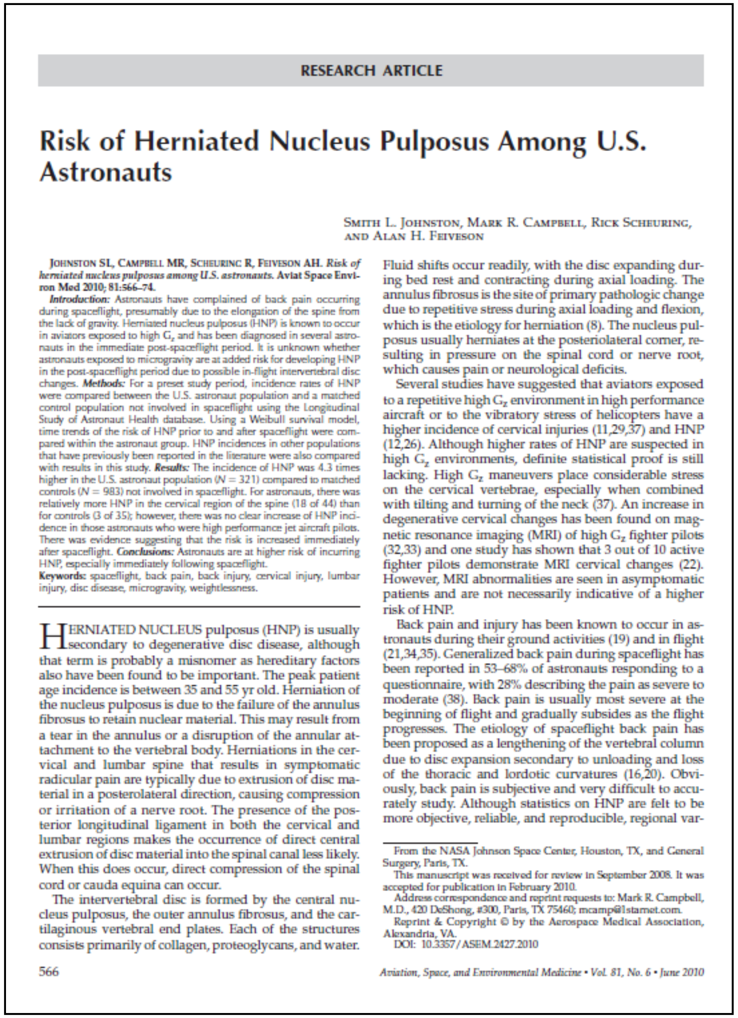


*The radiation exposure (effective dose) from one low-dose CT scan of the chest is ~1.5 mSv and a regular-dose CT scan of the chest is ~7-10 mSv.

*A typical 6 month ISS mission effective dose is in the range of 50-80 mSv.

Post-flight Spine Conditions





RESEARCH ARTICLE

Risk of Herniated Nucleus Pulposus Among U.S. Astronauts

Smith L. Johnston, Mark R. Campbell, Rick Scheuring, and Alan H. Feiveson

Johnston SL, Campbell MR, Scheuring R, Feiveson AH. *Risk of herniated nucleus pulposus among U.S. astronauts.* **Aviat Space Environ Med 2010; 81:566–74.**

Introduction: Astronauts have complained of back pain occurring during spaceflight, presumably due to the elongation of the spine from the lack of gravity. Herniated nucleus pulposus (HNP) is known to occur in aviators exposed to high G_z and has been diagnosed in several astronauts in the immediate post-spaceflight period. It is unknown whether astronauts exposed to microgravity are at added risk for developing HNP in the post-spaceflight period due to possible in-flight intervertebral disc changes. ***Methods:*** For a preset study period, incidence rates of HNP were compared between the U.S. astronaut population and a matched control population not involved in spaceflight using the Longitudinal Study of Astronaut Health database. Using a Weibull survival model, time trends of the risk of HNP prior to and after spaceflight were compared within the astronaut group. HNP incidences in other populations that have previously been reported in the literature were also compared with results in this study. ***Results:*** The incidence of HNP was 4.3 times higher in the U.S. astronaut population ($N = 321$) compared to matched controls ($N = 983$) not involved in spaceflight. For astronauts, there was relatively more HNP in the cervical region of the spine (18 of 44) than for controls (3 of 35); however, there was no clear increase of HNP incidence in those astronauts who were high performance jet aircraft pilots. There was evidence suggesting that the risk is increased immediately after spaceflight. ***Conclusions:*** Astronauts are at higher risk of incurring HNP, especially immediately following spaceflight.

Keywords: spaceflight, back pain, back injury, cervical injury, lumbar injury, disc disease, microgravity, weightlessness.

HERNIATED NUCLEUS pulposus (HNP) is usually secondary to degenerative disc disease, although that term is probably a misnomer as hereditary factors also have been found to be important. The peak patient age incidence is between 35 and 55 yr old. Herniation of the nucleus pulposus is due to the failure of the annulus fibrosus to retain nuclear material. This may result from a tear in the annulus or a disruption of the annular attachment to the vertebral body. Herniations in the cervical and lumbar spine that results in symptomatic radicular pain are typically due to extrusion of disc material in a posterolateral direction, causing compression or irritation of a nerve root. The presence of the posterior longitudinal ligament in both the cervical and lumbar regions makes the occurrence of direct central extrusion of disc material into the spinal canal less likely. When this does occur, direct compression of the spinal cord or cauda equina can occur.

The intervertebral disc is formed by the central nucleus pulposus, the outer annulus fibrosus, and the cartilaginous vertebral end plates. Each of the structures consists primarily of collagen, proteoglycans, and water. Fluid shifts occur readily, with the disc expanding during bed rest and contracting during axial loading. The annulus fibrosus is the site of primary pathologic change due to repetitive stress during axial loading and flexion, which is the etiology for herniation (8). The nucleus pulposus usually herniates at the posteriolateral corner, resulting in pressure on the spinal cord or nerve root, which causes pain or neurological deficits.

Several studies have suggested that aviators exposed to a repetitive high G_z environment in high performance aircraft or to the vibratory stress of helicopters have a higher incidence of cervical injuries (11,29,37) and HNP (12,26). Although higher rates of HNP are suspected in high G_z environments, definite statistical proof is still lacking. High G_z maneuvers place considerable stress on the cervical vertebrae, especially when combined with tilting and turning of the neck (37). An increase in degenerative cervical changes has been found on magnetic resonance imaging (MRI) of high G_z fighter pilots (32,33) and one study has shown that 3 out of 10 active fighter pilots demonstrate MRI cervical changes (22). However, MRI abnormalities are seen in asymptomatic patients and are not necessarily indicative of a higher risk of HNP.

Back pain and injury has been known to occur in astronauts during their ground activities (19) and in flight (21,34,35). Generalized back pain during spaceflight has been reported in 53–68% of astronauts responding to a questionnaire, with 28% describing the pain as severe to moderate (38). Back pain is usually most severe at the beginning of flight and gradually subsides as the flight progresses. The etiology of spaceflight back pain has been proposed as a lengthening of the vertebral column due to disc expansion secondary to unloading and loss of the thoracic and lordotic curvatures (16,20). Obviously, back pain is subjective and very difficult to accurately study. Although statistics on HNP are felt to be more objective, reliable, and reproducible, regional var-

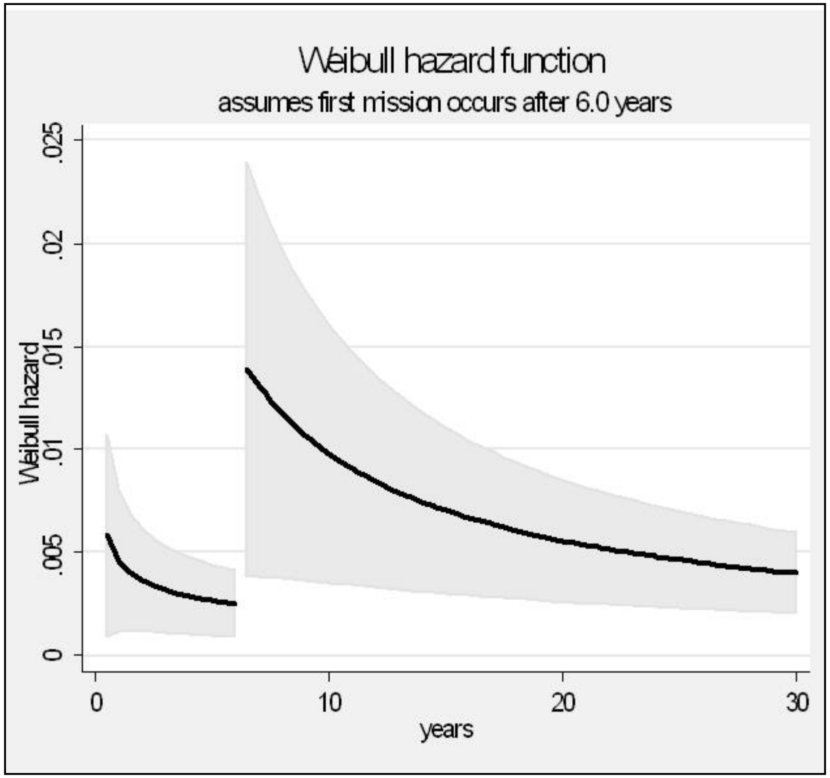
From the NASA Johnson Space Center, Houston, TX, and General Surgery, Paris, TX.

This manuscript was received for review in September 2008. It was accepted for publication in February 2010.

Address correspondence and reprint requests to: Mark R. Campbell, M.D., 420 DeShong, #300, Paris, TX 75460; mcamp@1starnet.com.

DOI: 10.3357/ASEM.2427.2010

Results



- HNP incidence is not related to in-flight back pain (SABP)
- More multiple events in astronauts
- No correlation with BMI or Age or Time Period
- Slightly less incidence with women (both astronauts and controls), same statistical results

Conclusions

- Astronauts have a greatly increased incidence of HNP (4.3 X)
- Risk is greatest immediately following space flight (35.9 X during the first year post-mission)
- The risk of cervical HNP is especially high (21.4 X), not related to previous High Gz experience
- Pre-mission astronauts have an increased incidence of HNP due to previous High Gz environment experience

Post flight HNP revisited

Assessing the Effect of Spaceflight on the Propensity for Developing Disc Herniation

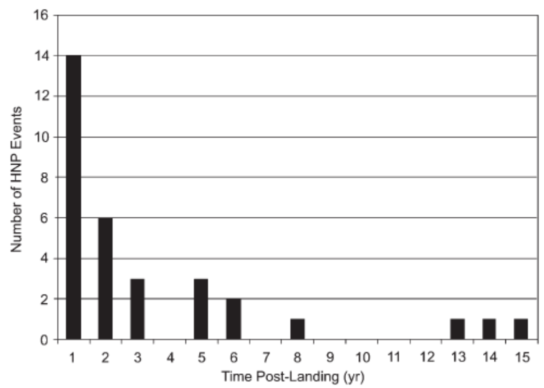
Alan H. Feiveson,[1] Claudia M. Méndez,[2] Jeffrey T. Somers[3]

[1]NASA Johnson Space Center, [2]MEI Technologies, [3]Wyle Science, Technology and Engineering Group

Background:

- In a retrospective study following 330 U.S. astronauts over a span of approximately 50 years, 51 of the astronauts were found to have experienced pronounced disk herniation (HNP = *herniated nucleus pulposus)* either during their careers as active astronauts or after retirement.
- (Earlier study) The number of cases of HNP appears to be highest in the first year after mission landings, and then drops off precipitously afterwards.

Figure 1. HNP Cases (earlier study*)



* Johnston S l, Campbell MR, Scheuring R, Feiveson AH. Risk Of Herniated Nucleus Pulposus among U.S. Astronauts. Aviat Space Environ Med 2010; 81: 566 – 74

.

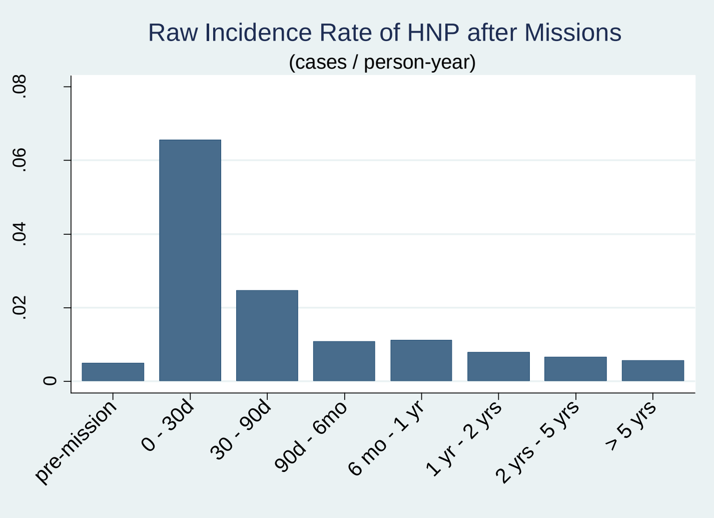
Disk herniation

Post flight HNP revisited

Assessing the Effect of Spaceflight on the Propensity for Developing Disc Herniation

Does spaceflight increase the risk of developing a HNP?
If so, when does the effect “wear off”?

Figure 2. HNP Incidence Rates



Pro: Higher incidence of HNPs relatively soon after space missions.

Con: Substantial number of HNPs before astronauts’ first missions or well after their last missions.

Disk herniation

Post flight HNP revisited

Assessing the Effect of Spaceflight on the Propensity for Developing Disc Herniation

Does spaceflight increase the risk of developing a HNP?

Data

- 330 U.S. Astronauts
- Observed from entry into astronaut corps to date of first HNP, or last negative exam.
  - Launch and landing dates for each mission.
  - Type of landing vehicle (Shuttle or capsule)
  - Dates of physical exams
  - Exam outcomes: HNP or no HNP
- 745 total missions (0 – 7 missions per astronaut)
- 1075 total observations (including 330 prior to first mission)
- Demographic (gender, age, weight, height)

Disk herniation

Russian Experience

- Drs. Oleg Kotov & Ilya Rukavnishkov
  - Salut 7 mission: Cosmonauts had 1-5 cm spinal elongation from pre-flight
    - Y. Gargarin experienced 108 mm
  - Spinal pain was reported in most cosmonauts early in flight
- "Transverse Stiffness" in muscle is measured by muscle viscosity myometric analysis, correlated with EMG data to confirm changes
  - Concluded muscle stiffness in space related to spinal elongation
  - Approaches peak within 24-48 hrs in μg
  - *MRI data pre-post-flight confirms flattening of the spinal curvatures with concomitant increased IVD height
  - Dry immersion study is a reliable analog
  - Axial loading prevents pain signals and IVD changes
  - Contrast to UCSD approach: measure interspinous movement with fluoroscopic kinematics and indirectly determine muscle stiffness

Russian Experience cont'd…

- Summary

Axial unloading in μg → spinal curve flattening → increased IVD height → spine pain → → → spinal muscle atrophy

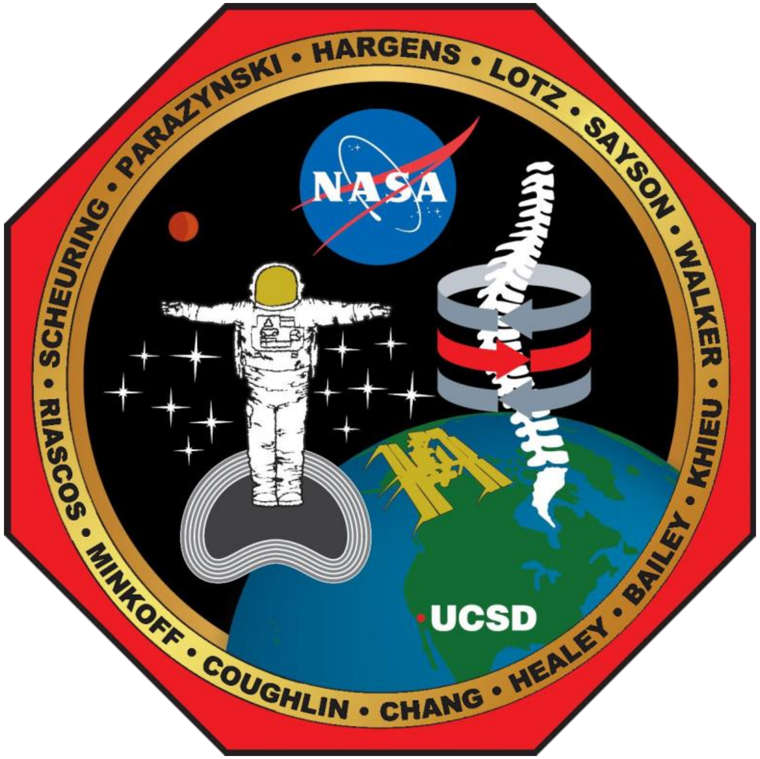
"Pain is a signal that the body has changed"

*Mission assigned cosmonauts have pre- and lost-flight screening lumbar spine MRIs every 2 hrs

Russian Experience cont'd…

- Post-flight reconditioning program
  - Cosmonauts undergo a gradually accelerated re-adaptation to 1g over a period of 6 months
  - R+0-R+30
    - Massage
    - Swimming
    - Proprioception
    - Light cardio
  - R+30-R+180
    - Gradually re-introduce loading exercises
    - Aerobic conditioning (running)
    - Continue Massage

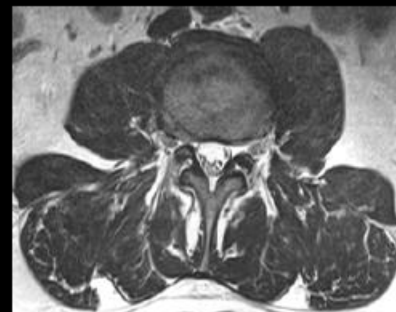
UCSD IVD Project



Methods

Supine MRI (3T)

Lumbar lordosis (L1-S1)
Water content
Disc health
Muscle functional cross-sectional area
Vertebral endplate and disc pathology



Pre-flight, R+1, R+45

Upright MRI (0.6T)

Lumbar lordosis (L1-S1) in upright posture (load bearing)

Pre-flight, R+1

Functional testing

Timed Biering-Sorenson test (seconds) for lumbar paraspinal muscle endurance

Pre-flight, R+1

Dynamic radiographs

Intervertebral ROM in active (standing) and passive (lying) postures

Pre-flight, R+1

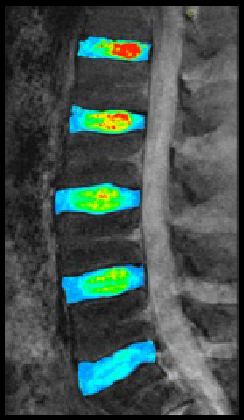
Negligible changes in disc swelling

No significant changes in **disc height** following spaceflight

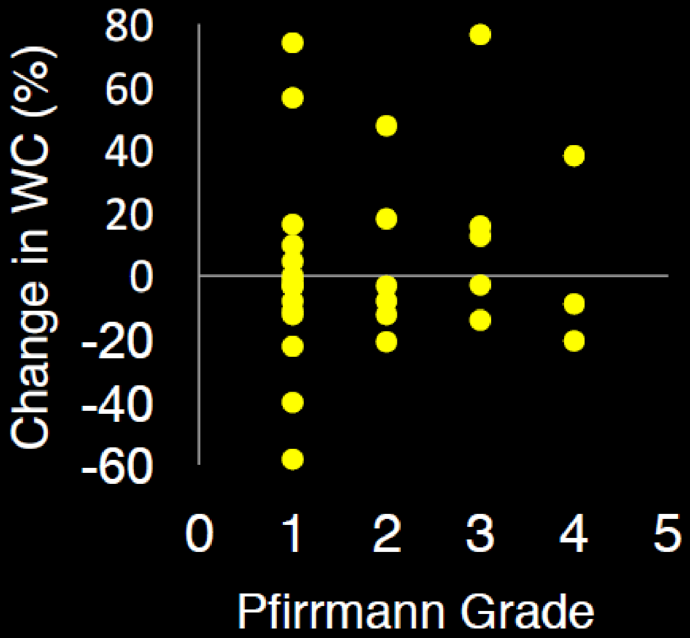
(Chang et al. 2016)

No significant changes in **disc water content** following spaceflight

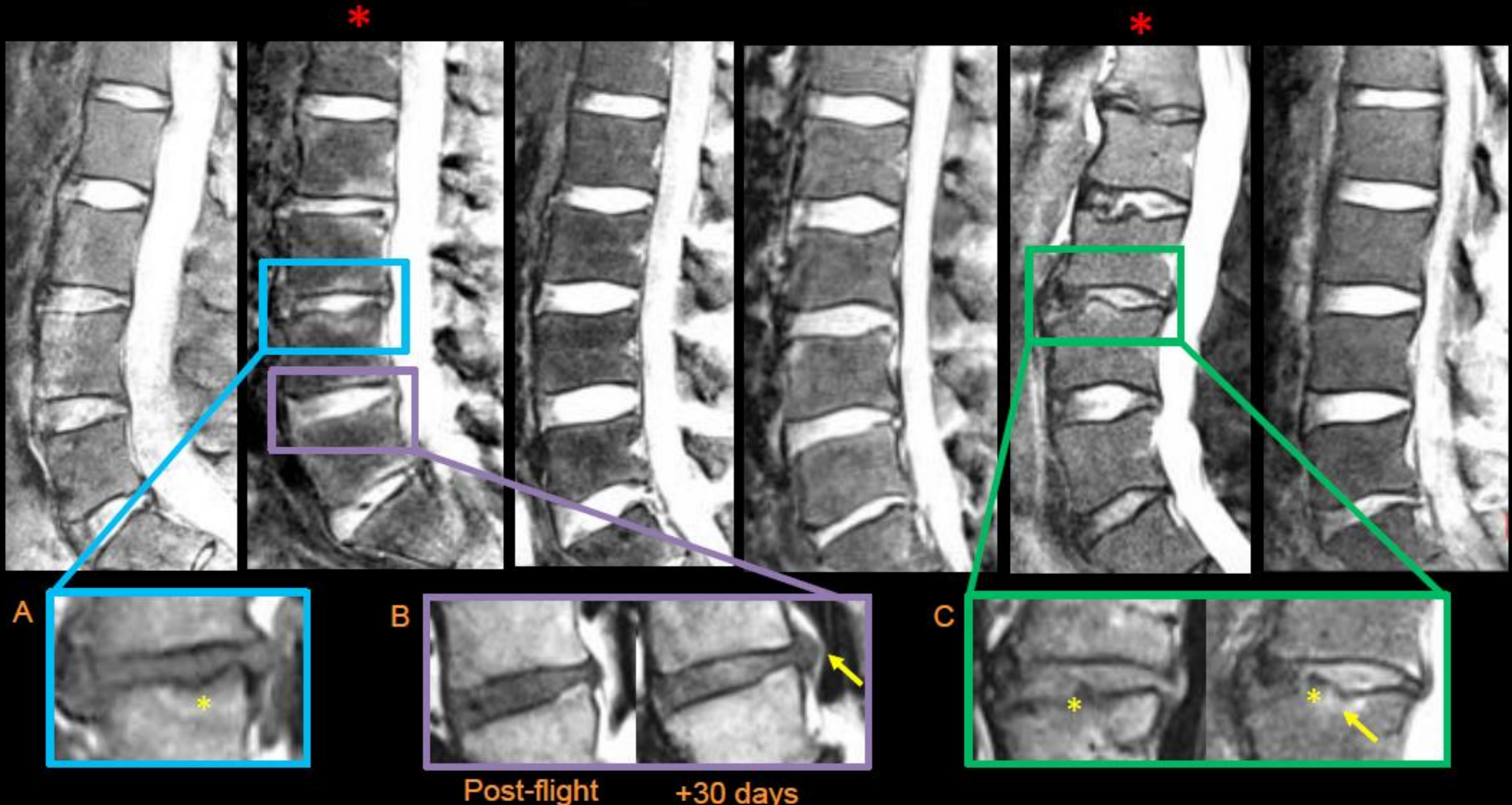
(Bailey et al. 2018)



IVD T2 Mapping

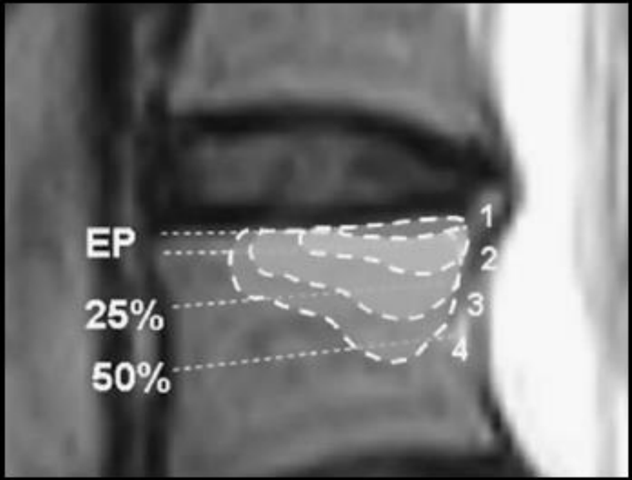


Crew with Chronic Back Pain More Likely to Have Endplate Lesions



Endplate Lesions include 'irregularities' and Modic Changes

MRI Findings May Associate with Future Pain

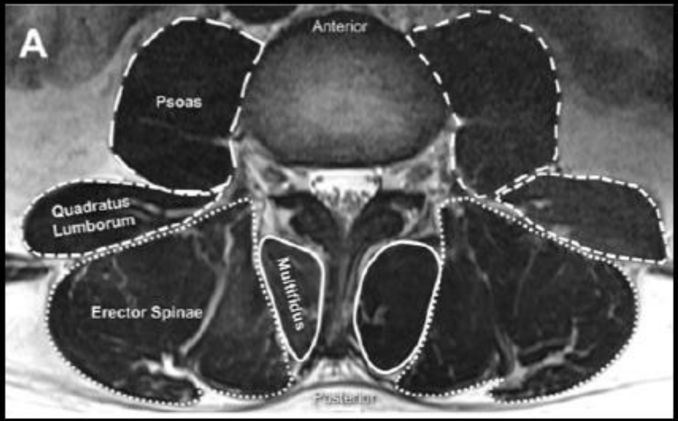


Modic Type 1 at baseline predicted worse pain over subsequent 14 months.
OR 6.2 (1.9-20.2)
Jensen, 2012

Endplate damage progresses over time and correlates with disabling back pain
Munir, 2018

Change in MC1, endplate damage, and disc height associate with change in ODI
Luoma, 2016

Lumbar paraspinal muscle changes



Post-flight significant changes found for:

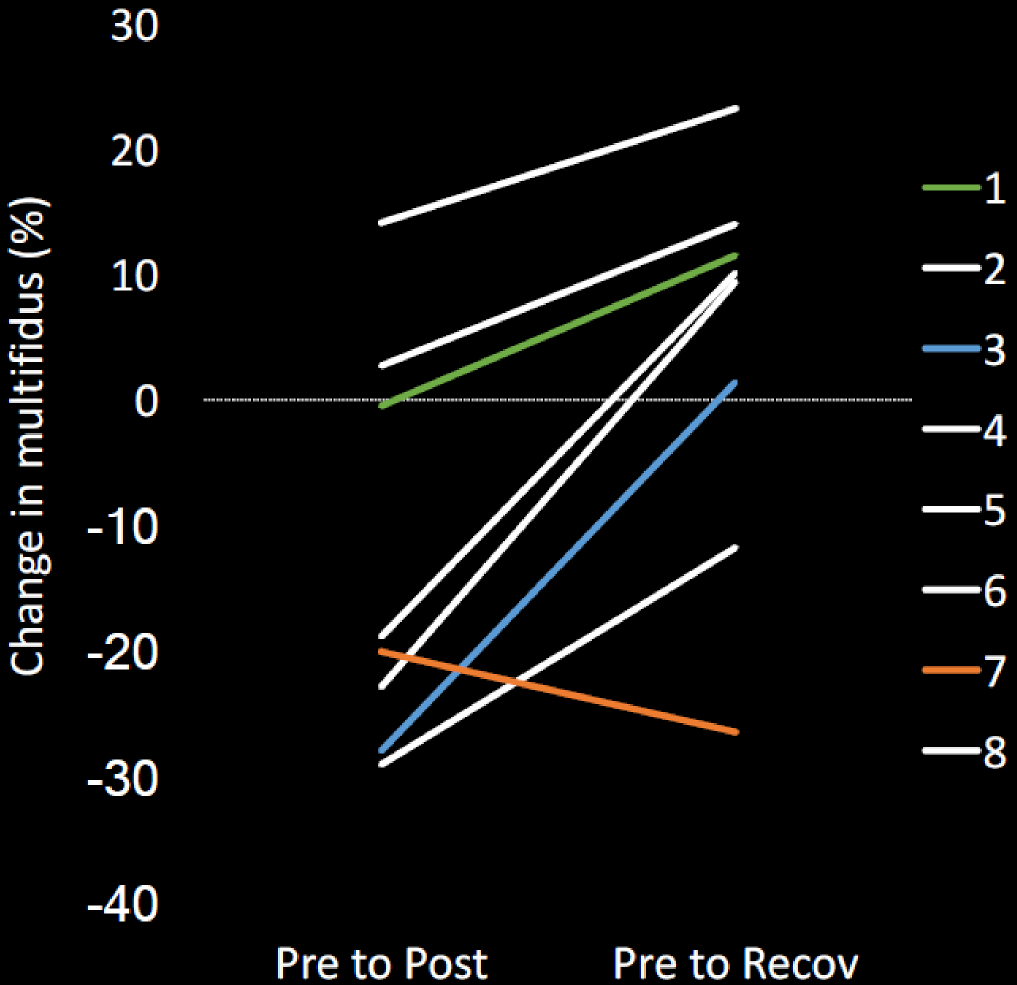
Multifidus lean muscle content (-13.5%, $p<0.05$)

On average, recovered to +4.1% pre-flight

Quadratus Lumborum lean muscle content (-13.7%, $p<0.05$)

On average, recovered to +1.8% pre-flight

Crew with severe post-flight spine conditions had highest levels of pre-flight multifidus fat content



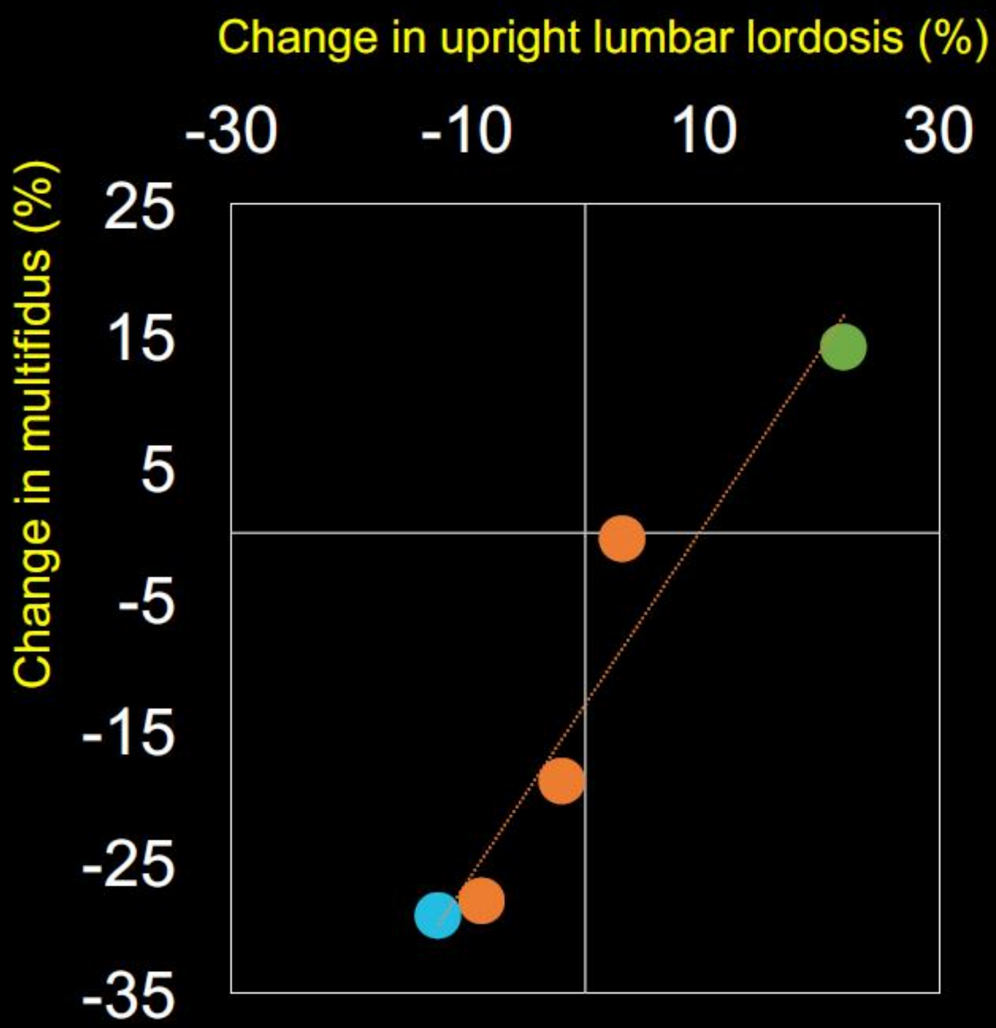
38% pre-flight multifidus fat Infiltration

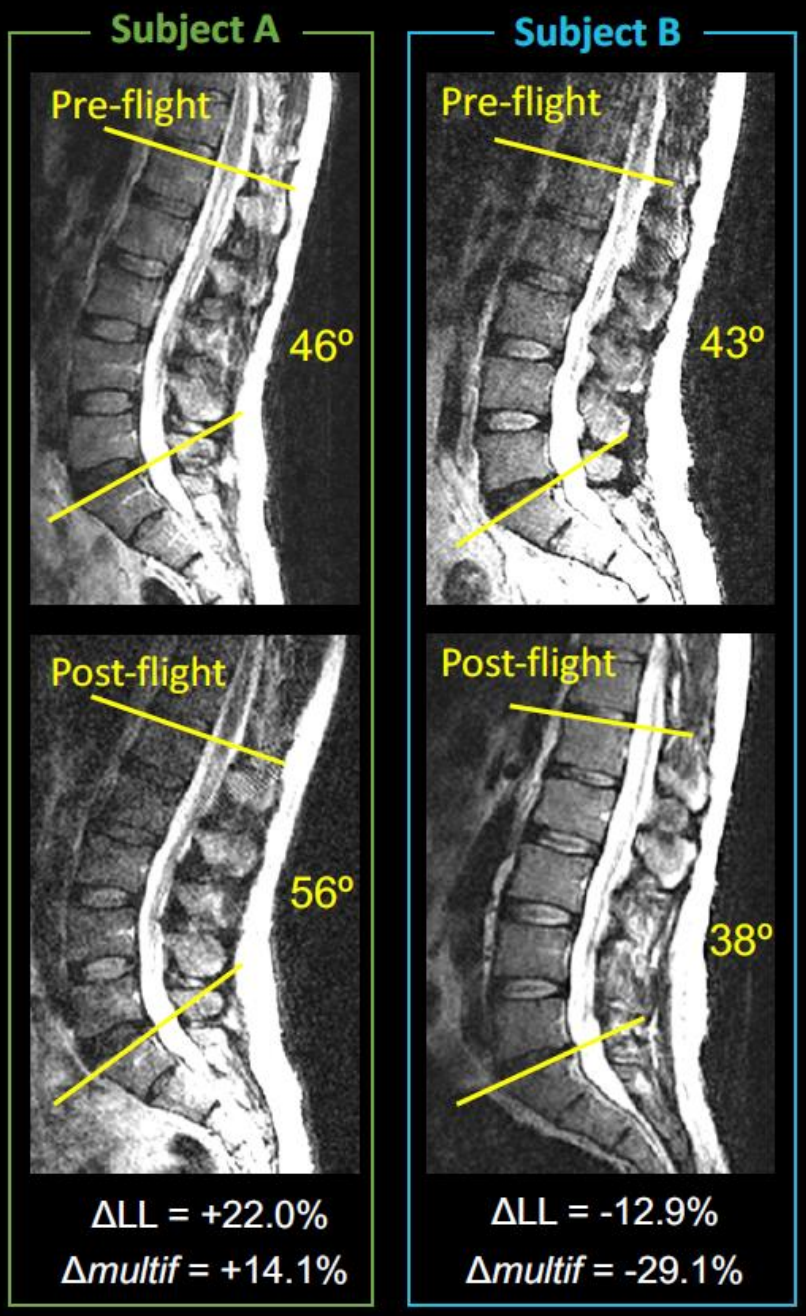
23% pre-flight multifidus fat Infiltration

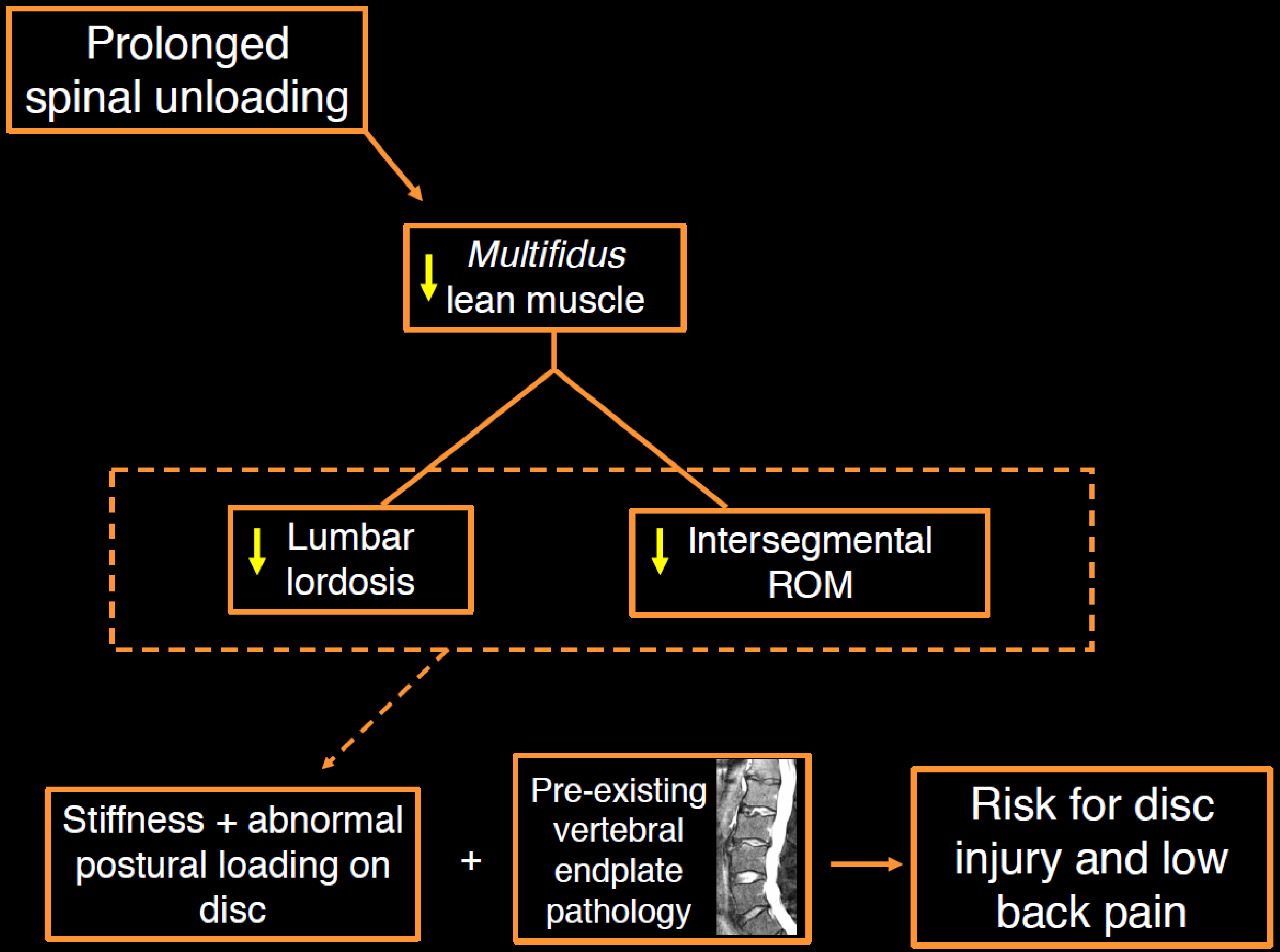
43% pre-flight multifidus fat Infiltration

Post-spaceflight increase in multifidus = increase in lordosis

Post-spaceflight decrease in multifidus = decrease in lordosis






Prolonged spinal unloading
Multifidus lean muscle
Lumbar lordosis
Intersegmental ROM
Stiffness + abnormal postural loading on disc
+
Pre-existing vertebral endplate pathology
Risk for disc injury and low back pain

Summary

Known

- Loss of paraspinal and other core musculature
- Anthropomorphic adaptation to weightlessness:
  - -spinal elongation
  - -disc expansion
  - -lack of compression
  - -loss of cervical/lumbar lordosis
- Astronaut age and occupational risk
- The possible contributions of exercise countermeasures as we currently perform them
- Post-flight activities in relation to landing and time to loading the axial skeleton

Unknown

- True Disk pathology, pre-dating flight or developing inflight
- In-flight pain generator(s)
- Long-term alterations of vertebral end plate/IVD physiology
- Contribution to facet arthrosis
- Level of resistive load in microgravity required to maintain bone and muscle integrity

Discussion & Recommendations

1. Do the inflight changes in the lumbar spine contribute to immediate spine pain and delayed post-flight spine disease?
2. Should we add pre- and post-flight non-contrasted lumbar spine MRI to astronaut selection and mission assigned occupational medicine surveillance rqts?
   a. Should we consider implementing on orbit use of ultrasound for diagnostic imaging?
3. Does loss of hip flexion, erector spinae, multifidus, longissimus, spinalis, etc. strength and other spine stabilizing muscles contribute to the etiology of post-flight back pain?
   a. If so, is the current in- and post-flight training program the best we can do to reduce this risk?
4. In astronauts with known pre-existing spinal disease, are the current preventive, clinical and rehabilitation interventions the best we can do?
5. With regards to future microgravity exercise devices, what capability should be added to mitigate the spinal changes discussed?

Panel Recommendations

1. The panel believes, based on the supporting data and experience of the panel, that in-flight changes in the lumbar spine contribute to immediate spine pain and delayed post-flight spine disease.

2. The panel believes, based on the supporting data and experience of the panel, that loss of hip flexion and weakening of spine stabilizing muscles contributes to the etiology of post-flight back pain.

3. The panel recommends adding pre- and post-flight non-contrast lumbar spine MRI imaging to mission assigned crew members for the purposes of occupational surveillance and for the prevention or minimization of spaceflight-related back pain and injury. The panel currently recommends against MRI imaging for use in astronaut selection standards.

Panel Recommendations

4. The panel recommends further incorporating Functional Movement Screening into pre- and post-flight conditioning and rehabilitation programs. The panel also encourages earlier intervention of low back pain with more invasive modalities, such as epidural steroid injections, on a case by case basis depending on what abnormalities can be seen on MRI imaging. Finally the panel recommends the incorporation of pre-flight corrective exercises for conditioning of the deep core stabilizing muscles prior to flight.

5. The panel recommends incorporating in-flight exercise modalities that target deep core stabilizing muscles, including but not limited to, resistive exercises outside the sagittal plane, as well as all other planes including rotational into the design of future exercise hardware for deep space exploration missions. The panel also recommends considering a rowing capability for deep space missions, however acknowledges that this capability has been minimally tested in a microgravity environment and further evaluation is warranted.

MSK Ultrasound

- Used to diagnose musculoskeletal injuries and guide treatment plans and predict return to duty timeframe
- MSK conditions occurring on-orbit
  - Recurrent knee pain
  - Hamstring strains*
  - Finger dislocations
  - Foot trauma related to CEVIS
  - EMU doffing shoulder injury
  - Low back pain/injury
  - Cervical spine pain

*Used to diagnose on-orbit in ISS crewmember