Musculoskeletal Injuries in US Astronauts

Injury prevention strategies, including pre-flight EVA fitness training, return to flight following injuries, and post-flight reconditioning

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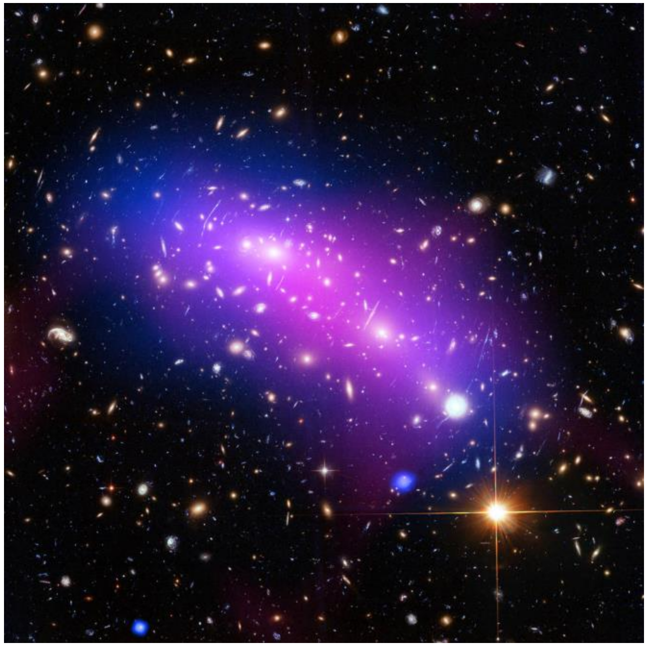
MSK Medicine and Rehabilitation Program

- Background
- Terrestrial experience
  - Initial investigation into MSK injuries
  - MSK Medicine Program
  - Training injuries
  - NBL EMU Work Hardening Program
  - Return to duty
  - Post-flight reconditioning program
- Inflight musculoskeletal conditions
- Lunar Surface Operations
- Post-flight injuries



Colliding galaxies, Hubble Space Telescope, March, 2016

Terrestrial experience

- First study to look at *terrestrial*-based musculoskeletal injuries in US astronauts
- Genesis of the Astronaut Strength, Conditioning and Rehabilitation (ASCR) specialists

Musculoskeletal Injury Review in the U.S. Space Program

RICHARD T. JENNINGS, M.D., M.S., and JAMES P. BAGIAN, M.D.

JENNINGS RT, BAGIAN JP. ***Musculoskeletal injury review in the U.S. space program.*** **Aviat Space Environ Med 1996; 67:762–6.**

Astronauts in NASA's space program are expected to remain fit to complete their on-orbit tasks and to function effectively in the event of contingency operations. Due to the generally self-directed exercise program and reliance on competitive sports and running for conditioning, plus limited emphasis on training techniques and rehabilitation, there have been a surprising number of orthopedic injuries and surgeries in this small adult population. This article examines the orthopedic injury history of U.S. astronauts during the period from 1987–95. The type of injury, activity involved, and subsequent surgical interventions are cataloged. There were a total of 26 fractures, 36 serious ligament, cartilage, or soft tissue injuries, and 28 orthopedic surgical procedures in this adult group with a mean astronaut corps size of only 94. Women accounted for 16% of the study population but accounted for only 1 of 28 surgical procedures. Knee injuries required surgical intervention 19 times. Running, skiing, and basketball were most frequently associated with injuries. The descriptive data regarding frequency of adverse events and activity associated with injuries is presented. These injury patterns are analyzed and suggestions made for future improvement, including decreased reliance on running and competitive athletics for conditioning, improved personal fitness training preflight, and coordinated rehabilitation postflight. Also recommended is the use of a lap pool for preflight total body fitness training, since swimming provides conditioning to those muscle groups used during spaceflight, and for variably weighted gravity rehabilitation postflight.

NASA ASTRONAUTS are informally expected to maintain a certain degree of fitness to perform their critical duties. As with all physical training programs, some risk is associated with exercise, even when appropriately supervised (4,9–11,14,17,21). NASA's fitness program has generally been voluntary and self-directed with minimal coordination of initial individual assessment, equipment safety training, or identification of job-related personal fitness targets. Postflight activity-oriented science data collection has actually been associated with causing new injuries. There has been no postflight rehabilitation program during the shuttle era until the advent of the long duration flights to the Mir space station. The lack of a coordinated fitness and rehabilitation program has resulted in reliance on self-motivation and primarily competitive athletics, unsupervised gym activities, and running for preflight aerobic and strength conditioning and postflight rehabilitation. This approach may not be totally causal, but has been associated with a surprising number of orthopedic injuries, surgical procedures, and lost work and training time. This article reviews the NASA astronaut orthopedic injury statistics from 1987–95, examines the U.S. and Russian approaches to crew fitness, and suggests potential improvements to the astronaut training and rehabilitation program.

METHODS

All NASA astronauts receive their health care through the Flight Medicine Clinic (FMC) at the Johnson Space Center. During the period between January 1987 and March 1995, all reported injuries seen at the FMC were recorded in a database as to the injury, cause, and subsequent treatment. The number of active astronauts during the 99-month study period varied from 80–108, with a mean corps size of 94. The number of female astronauts ranged from 12–19, except for March 1995 when there were 22. The women's mean during the study was 15. All injuries, including those requiring surgical intervention, were supervised by the flight surgeons at the FMC, although specialist referral was provided when appropriate. Astronauts who were assigned to flights during the period were prohibited from participating in some activities such as skiing, softball, or contact sports. About one-half of the active astronauts are assigned to flights at any one time. Injuries resulting from two aircraft accidents that caused two astronaut deaths were not included in the study.

RESULTS

Fractures

There were 26 events that resulted in fractures. The location and number of separate occurrences are listed below:

Ribs	5
Tibia	4
Fingers	3

From the University of Texas Medical Branch, Galveston, TX.

This manuscript was received for review in July 1995. It was revised and accepted for publication in November 1995.

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Terrestrial MSK Injury in US Astronauts[1]

Ribs 5	Running 7
Tibia 4	Snow Skiing 4
Fingers 3	Basketball 2
Toes 3	MVA 2 (1 motorcycle)
Metatarsal 2	Household 2
Radius 2	Softball 1
Medial Malleolus 1	Water Skiing 1
Talus 1	Horse 1
Fibula 1	Soccer 1
Metacarpal 1	Training 1
Os calcis 1	Other than Athletic 4
Humerus 1	
Face 1	

Fractures and physical activities associated with fractures

Knee 19
Neck and low back 8
Shoulder 2
Ankle 1
Foot 1

Orthopedic surgeries in US astronauts

[1]Jennings RT, Bagian JP. *Aviation, Space, and Environmental Medicine; Vol 67, No. 8 9 August 1996*

Terrestrial MSK Injury in US Astronauts

CONCLUSION

*"**NASA astronauts are generally competitive and desire fitness. Athletic activities that result in fitness are associated with a certain risk of injury due to accident, overuse, or training injury**. Dependence on self-regulated training, running, and competitive sports for conditioning has resulted in a relatively high level of injury and subsequent orthopedic surgery in this very small group. Even though the outcome of these injuries has generally been favorable, with minimal permanent physical deficits, **it is probably time to move beyond documentation of injuries and treatment to providing a program that strives to prevent or mitigate training related injury.** Several changes could assure a better outcome. Among these are the **employment of fulltime training staff for preflight, inflight, and post-flight conditioning/rehabilitation, cross training, and less reliance on running**. The addition of a lap pool for swimming would be helpful for providing a more rational method to insure preflight total fitness as well as post-flight variably weighted rehabilitation."*

Richard Jennings, MD Jim Bagian, MD, August,1996.

MSK Medicine and Rehabilitation Program

- Objectives

MSK Medicine and Rehabilitation Program

- Space Act Agreement
  - Orthopedic Surgery and Primary Care Sports Medicine Program at Methodist Hospital
  - Weekly orthopedic clinic at JSC
- Revise and update the astronaut selection standards
- Certification in Musculoskeletal Ultrasound

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
2101 NASA Parkway
Houston, TX 77058-3696

Musculoskeletal (MSK) Medicine
and Rehabilitation Project
Project Plan

April 2012

Center of Excellence

MSK Medicine and Rehabilitation Program

- Benefits
  - Identify risk factors for injury
  - Diagnosis and treatment kept “in-house”
  - Improved injury reporting and tracking
  - **Limit off-site time** in orthopedic consults unless deemed necessary for surgery
  - Provide cutting edge orthopedic care
- And…

Photo courtesy of www.crossfitoneworld.typepad.com

Orthopedic Consults at NASA since 2012

- Total orthopedic consults seen in the Wednesday clinic from 2012-current (March, 2016)
  - 246 total visits*
    - 180 “new” pts
    - 66 follow up visits
  - Astronaut time (estimated)
    - BTW 832-1,248 hrs
  - Cost (if NASA were billed)
    - Total cost (savings) to NASA: > $140,000

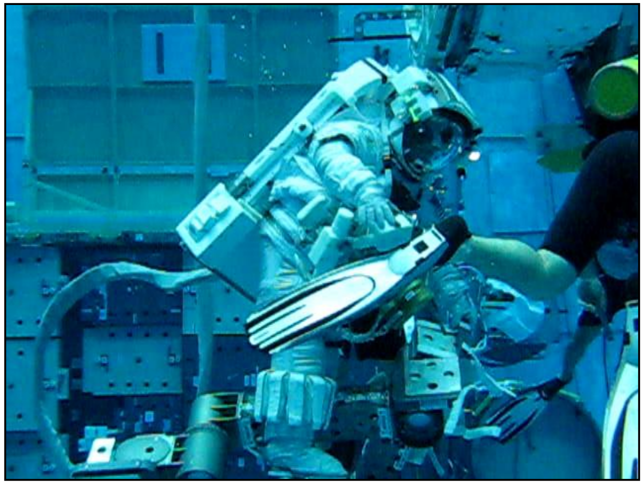
*estimated

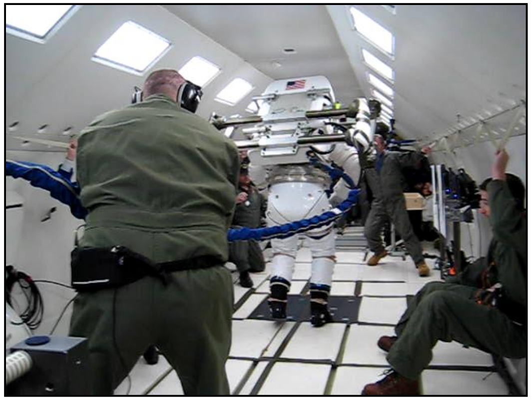
Musculoskeletal Ultrasound (MSK US)

- Incorporation of musculoskeletal ultrasound in diagnosis and treatment
- Collaborations
  - Detroit Medical Center
  - Mayo Clinic
  - Andrews Institute

Astronaut Training Injuries

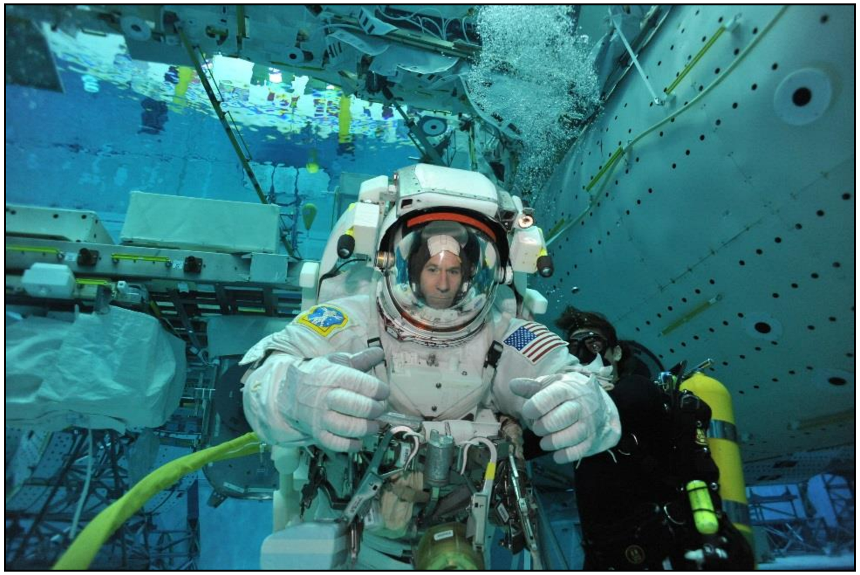
- Activities
  - Neutral Buoyancy Lab
  - T-38 flight operations
  - Parabolic flight a.k.a. Vomit Comet
  - Analog environments
  - Physical fitness training





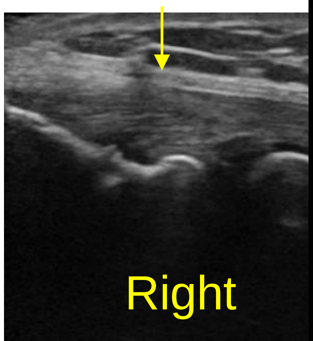
Extravehicular activity **M**obility **U**nit (EMU) Training Injuries

- **Shoulder**
  - rotator cuff tendonitis, SASD bursitis, LHBT tenosynovitis, SLAP lesion, impingement syndrome, anterior impingment (subscapularis), AC joint pain, GH joint pain
- **Elbow**
  - lateral epicondylitis, radial/cubital tunnel syndromes
- **Forearm/wrist**
  - Dequervan's tenosynovitis, Extensor Pollicis Longus (EPL) tendonitis, carpal tunnel syndrome
- **Fingers**
  - onycholysis
- **Spine**
  - cervical, thoracic strain, lumbar spasm



Upper extremity conditions related to EMU NBL training

Normal right EPL in S

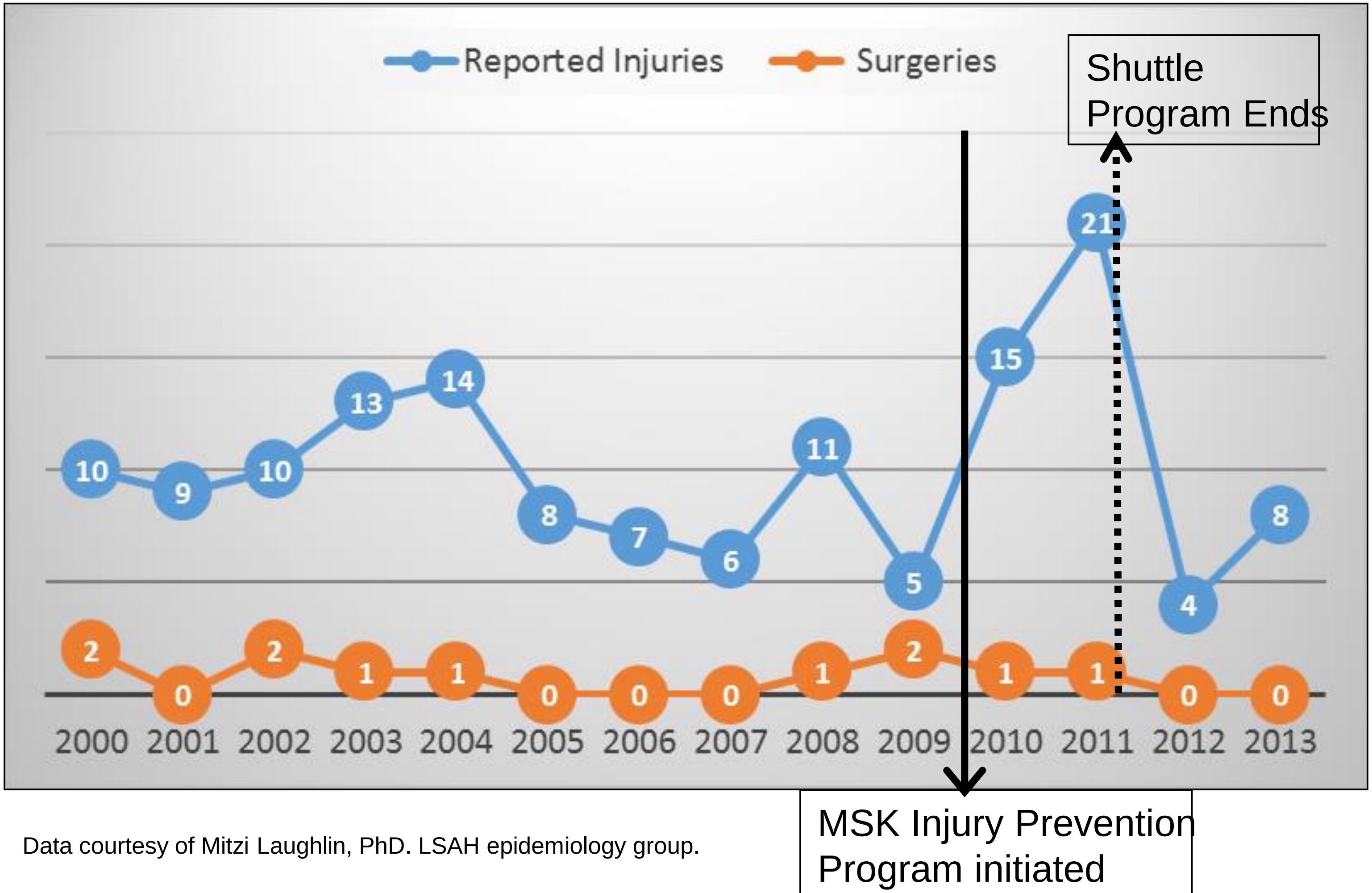


Normal right CET in L

sor)
PL)

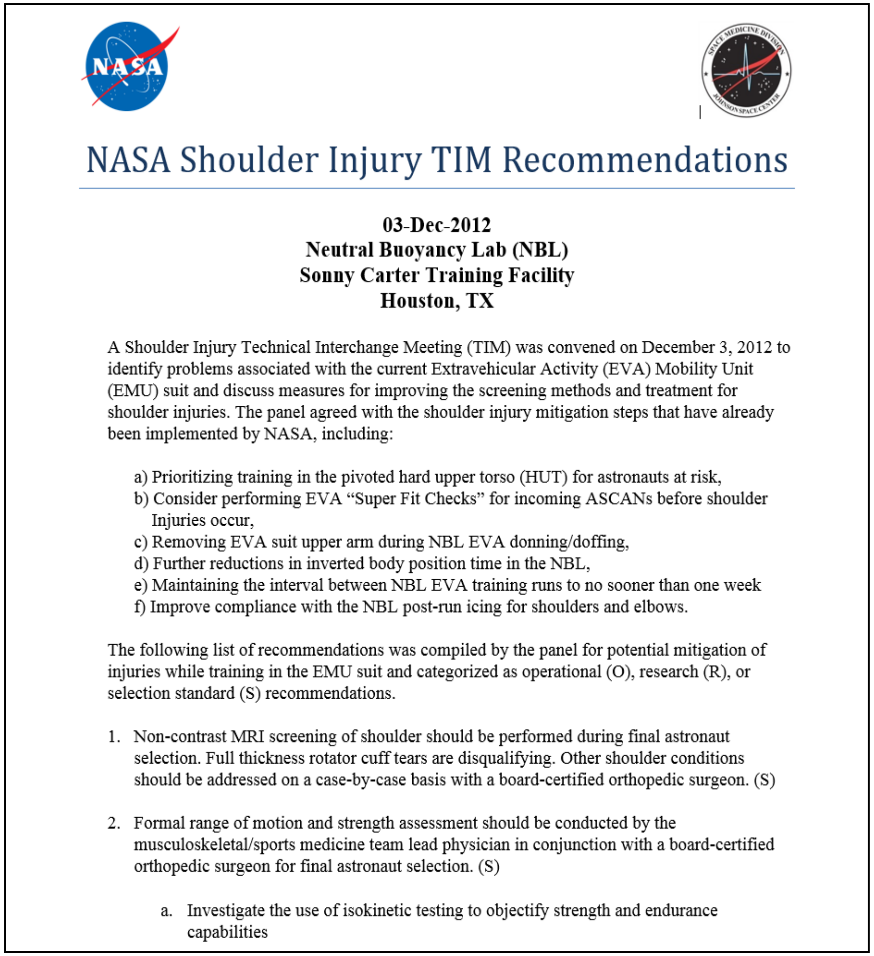
or tendon
s

Number of Reported Shoulder Injuries & Surgeries by Year



Data courtesy of Mitzi Laughlin, PhD. LSAH epidemiology group.

NBL EMU Shoulder Injury TIM



NASA Shoulder Injury TIM Recommendations

03-Dec-2012
Neutral Buoyancy Lab (NBL)
Sonny Carter Training Facility
Houston, TX

A Shoulder Injury Technical Interchange Meeting (TIM) was convened on December 3, 2012 to identify problems associated with the current Extravehicular Activity (EVA) Mobility Unit (EMU) suit and discuss measures for improving the screening methods and treatment for shoulder injuries. The panel agreed with the shoulder injury mitigation steps that have already been implemented by NASA, including:

a) Prioritizing training in the pivoted hard upper torso (HUT) for astronauts at risk,
b) Consider performing EVA "Super Fit Checks" for incoming ASCANs before shoulder Injuries occur,
c) Removing EVA suit upper arm during NBL EVA donning/doffing,
d) Further reductions in inverted body position time in the NBL,
e) Maintaining the interval between NBL EVA training runs to no sooner than one week
f) Improve compliance with the NBL post-run icing for shoulders and elbows.

The following list of recommendations was compiled by the panel for potential mitigation of injuries while training in the EMU suit and categorized as operational (O), research (R), or selection standard (S) recommendations.

1. Non-contrast MRI screening of shoulder should be performed during final astronaut selection. Full thickness rotator cuff tears are disqualifying. Other shoulder conditions should be addressed on a case-by-case basis with a board-certified orthopedic surgeon. (S)

2. Formal range of motion and strength assessment should be conducted by the musculoskeletal/sports medicine team lead physician in conjunction with a board-certified orthopedic surgeon for final astronaut selection. (S)

   a. Investigate the use of isokinetic testing to objectify strength and endurance capabilities

- Shoulder experts (Orthopedic surgeons, PM&R specialists, Biomechanists) provided several recommendations for mitigating NBL EVA training shoulder injuries

NBL EMU Shoulder Injury Prevention Program

- 17 mitigation strategies

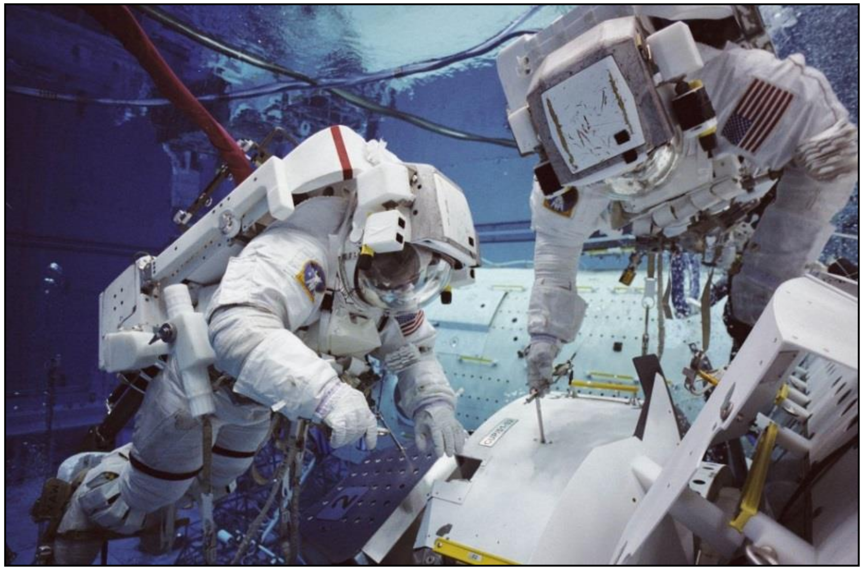
NBL EMU Shoulder Injury Prevention Program

Conclusions

- Since 2010, when the MSK Injury Prevention Program was initiated
  - Reported shoulder injuries have increased but that means more injuries are getting evaluated and ultimately treated.
  - On average, shoulder surgeries have decreased slightly but this was non-significant.

NBL EMU Work Hardening Program

- What does an astronaut need to be able to do, physically, in the EMU during an NBL run, to perform the function?
  - In terms of:
    - Endurance/stamina
    - Strength (force/time)
    - Range of motion
    - Position of the body relative to the task



"The best training for performing EVA in the NBL is actually doing EVA in the NBL."

Astronaut Suni Williams, CAPT, USN

NBL EMU Work Hardening Program

NASA EVA Functional Capacity Evaluation (FCE) and Work Hardening Program
Development Effort Summary
16-Sept-2013

In attendance:

CB: Serena Aunon, Dan Burbank, Tracy Caldwell-Dyson, Amy Ellison, Pat Forrester, Nicole Stott, Peg Whitson, Suni Williams
DX: Jordan Lindsey, Paul Dum
SD: Jamie Chauvin, Joe Dervay, David Hoellen, Smith Johnston, Eric Kerstman, Jim Locke, Bruce Nieschwitz, Rick Scheuring, Bill Tarver
SK: Lori Ploutz-Synder, Jamie Guined
XA: Jessica McLaughlin

I. Definitions
  a. Functional Capacity Evaluation (FCE):
    i. A comprehensive functional test designed to measure the maximum safe functional abilities of an employee across a broad range of physical capabilities.
  b. Work Hardening (WH):
    i. A program designed to improve the employee's strength, flexibility, and aerobic condition/endurance through exercises and activities that simulate or include the actual job functions

II. Background
  a. Recommendations from NASA EMU Shoulder Injury TIM, Dec. 2012:
    i. Develop an NBL functional capacity evaluation (FCE) for selection and operational evaluation by the ASCRs.
    ii. Develop a supervised *mandatory* rotator cuff and scapular stabilizer training program to be conducted within 6 months of initial NBL runs, with a pre-run fitness check.
    iii. Develop a "work hardening" program, to be performed on land before NBL training and following rehabilitation for injury or surgery.
  b. Crew input regarding EVA Fitness Program
    i. General comment: the EVA fitness program should include activities that improve suited performance in the NBL along with activities that prevent injury.
    ii. The current exercise program prepares astronauts well for most NBL activities. Note that the best physical training program for NBL activities is actually being in the EMU in the pool.
    iii. Shoulder flexibility for suited operations is very important, especially flexion, internal and external rotation.
    iv. Need to be able to push oneself physically in the pool. Therefore exercise programs should include activities that demand stamina training as well as strength.

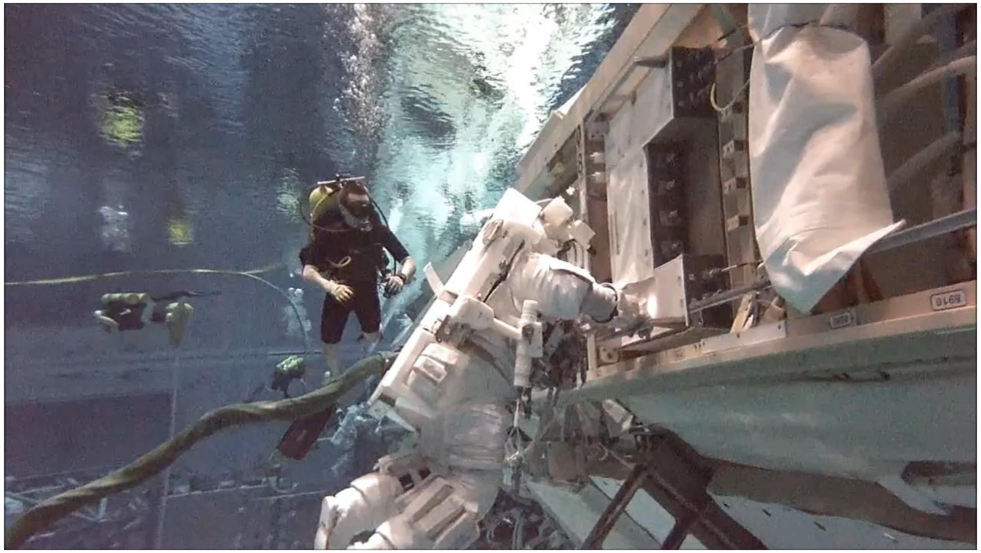
- Match physical fitness training with NBL tasks to improve EVA performance (from ASCRs)
  - **Grip tasks**- kettlebell swings, dumbbell crawl
  - **Shoulder tasks**- handstand push-ups, push press, Farmer's walk
  - **Core/Back**- RDL's, axle-wheel row, back extensions
  - **Articulating portable foot restraint (APFR) ingress**- Squats, lunges, box jumps
  - **Inverted operations**- Windmills, battle ropes, overhead bag toss

July 2015

WEEK 3

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
Up & Back Dynamic Warm-Up Routine	Up & Back Dynamic Warm-Up Routine	Up & Back Dynamic Warm-Up Routine	Up & Back Dynamic Warm-Up Routine	Up & Back Dynamic Warm-Up Routine
WARM UP EXERCISE	**WARM UP EXERCISE**	**WARM UP EXERCISE**	**WARM UP EXERCISE**	**HIGH VOLUME ENDURANCE**
20-15-10	3 Rounds	4 Rounds	3 Rounds	*Grind*
Pull Ups	15 Thrusters	25 Air Squats	10 Push Press	Every 30 secs
Dips	15 Push ups	15 Pushups	5 Knee to Elbow	2 burpees + 5 Dips for 10 rounds
Walking Lunges (on 15+1)			10 Half Moons (5 each side)	Then
STRENGTH & SKILL	**ENERGY SYSTEM DEVELOPMENT**	**STRENGTH & SKILL**	**ENERGY SYSTEM DEVELOPMENT**	10 Rounds
Then Super Set: Deadlifts (Heavy) & Hammer Row: 3 x 12, 4th set AMAP Presses	*Aerobic System*	Then Super Set: Dumbell Bench Press & Shrugs 3 x 12, 4th set AMAP	*ATP-CP (Phosphagen System)*	10 Pushups
	Treadmill- 5' @30-50% Max HR, 4' 80%, 3' 30-50%, 4' 80%, 3' 30-50%, 4' 80%, 3' 30-50%, 4' 80%, 5 min 30%.		Then 10 Rounds of Jacobs Ladder with weighted vest (1 min fast climb, 20 secs rest)	12 Swings
FINISHER WORKOUT		**FINISHER WORKOUT**		1 Lap Framers Walk
As Many Rounds as Possible in 20 Minutes of:		Row 800		Then
10 Push Ups		21 Renagecade Man Makers	**SHOULDER MAINTENANCE**	10 rounds
10 Front Squats	**SHOULDER MAINTENANCE**	Row 400	2 Rounds of 10	Run or row 100M
10 Weight Sit Ups	2x10: 3 Way Scarecrow (palms up, palms in and palms out) 5 lbs DB max	15 Renagecade Man Makers	Band Pull Apart Stayin' Alive	1 to 1 ratio (rest)
	2x10: Kneeling "Bottoms Up" Kettlebell Press (10 each arm)	Row 200	Band Pull Apart Reverse Fly	
	CORE DEVELOPMENT	9 Renagecade Man Makers	Hitchiker w/ DBs 5 lbs max	
	2x10: Shoulder Slides w/ towel, 2x10: Plank Shoulder Taps (1 tap each side = 1)	Rengacade ManMakers are DB burpeess (with no jump) to a Push-		
	2x10: Front Plank hip dips (1 tap each side = 1)		**CORE DEVELOPMENT**	
			3 x 30-45 sec holds Reverse Plank	
			2x10 Wood Chopper/Hay Baler w/ med ball	
			4 x Plank Walks 3 steps forward, 3 steps backwards	
10 MINUTES OF STRETCHING / FOAM ROLLER	**10 MINUTES OF STRETCHING / FOAM ROLLER**	**10 MINUTES OF STRETCHING / FOAM ROLLER**	**10 MINUTES OF STRETCHING / FOAM ROLLER**	**10 MINUTES OF STRETCHING / FOAM ROLLER**

NBL EMU Work Hardening Program



Stack translation

Dumbbell “astronaut” crawl

Axle-wheel row

NBL EMU Work Hardening Program

Windmills

Musculoskeletal Injuries in US Astronauts and Return to Duty

- Aerospace Medical Board (AMB)
  - Standards for astronaut selection, retention and approval for long duration spaceflight

REGION	TYPE OF INJURY	# OF CASES	SURGERY?	RTD	AMB WAIVER REQUIRED?
Shoulder	Rotator cuff tear-full thickness	4	Yes	T-38, NBL six months SF one year	No
	Rotator cuff tear-partial thickness	3	No	T-38, NBL six weeks, SF three months	No
	SLAP lesion Grade 2-4	3	Yes	T-38 three months, NBL six months, SF one year	No
	SLAP lesion Grade 1	2	No	T-38, NBL, SF three months	No
	Biceps tendon tear	2	Yes	T-38, NBL three months, SF six months	No
	Acromioclavicular joint	3	Yes	T-38, NBL three months, SF six months	No
Knee	Medial Collateral Ligament Sprain	6	No	SF six weeks	No
	Medial, Lateral Meniscus tear	6	Yes	T-38 three weeks, NBL six weeks, SF*	No
	Meniscus w/o repair	1	No	T-38, NBL, SF six weeks	No
	Anterior Cruciate Liagment tear- complete	2	Yes	T-38, NBL six months, SF one year	No
	Anterior Cruciate Liagment tear- partial	1	No	T-38, NBL , SF six weeks	No
	Osteoarthritis w/o replacement	3	Yes	T-38, NBL, SF six weeks	No
	Osteoarthritis w/ replacement	2	Yes	T-38, NBL six months, SDSF one year	Yes

*Unpublished data, courtesy
Rick Scheuring, DO, MS, 2013

In-flight MSK Conditions

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.

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DOI: 10.3357/ASEM.2270.2009

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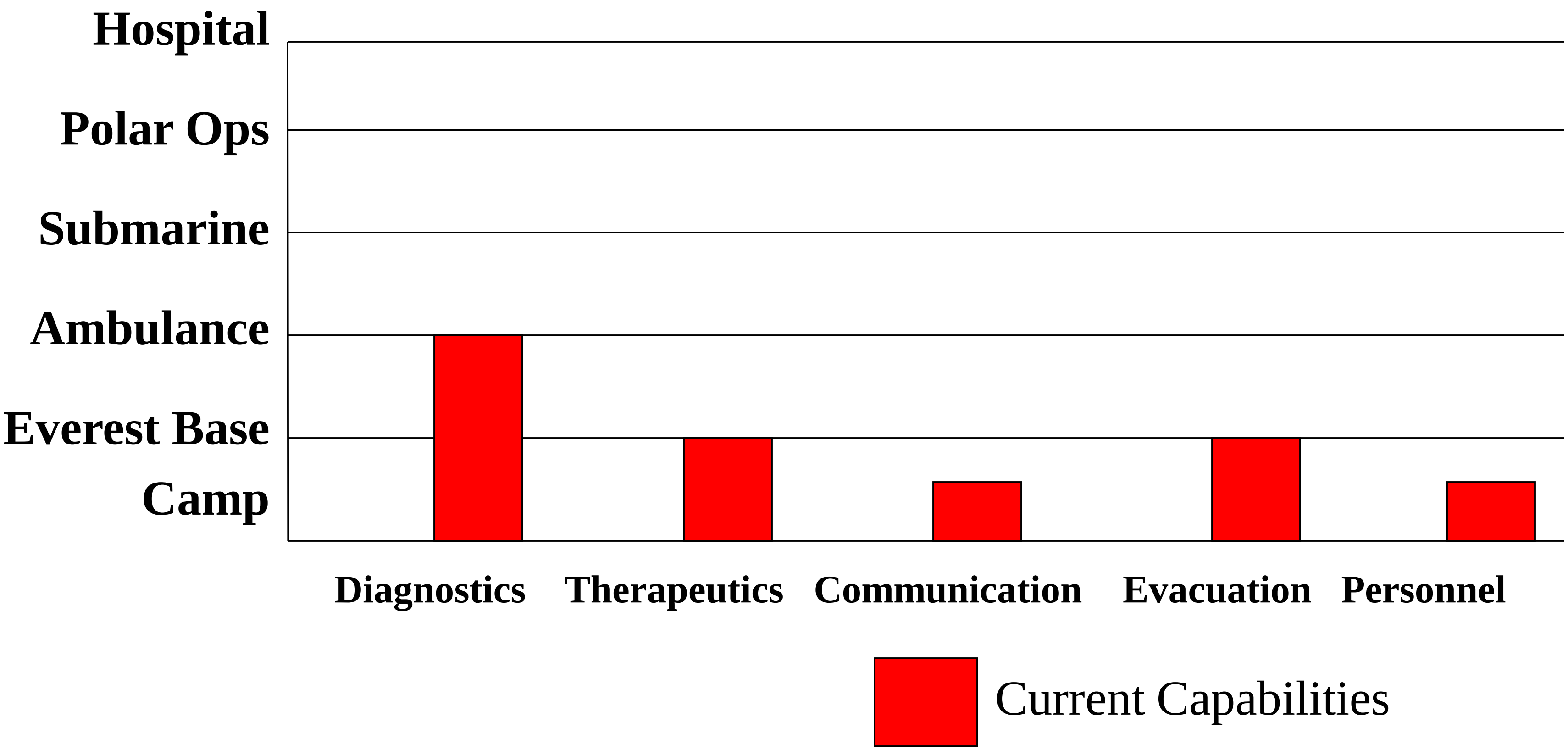
- Known
  - From STS-1 and STS-89 there was a greater *in-flight* injury rate among crewmembers than their age and sex-matched cohorts

Wear M. Injury rate of shuttle astronauts. The Longitudinal Study of Astronaut Health Newsletter, December, 1999, 8(2): 1,4.

- Unknown
  - The incidence, type and mechanism of in-flight injuries for US astronauts across all mission programs (Mercury to 2010)

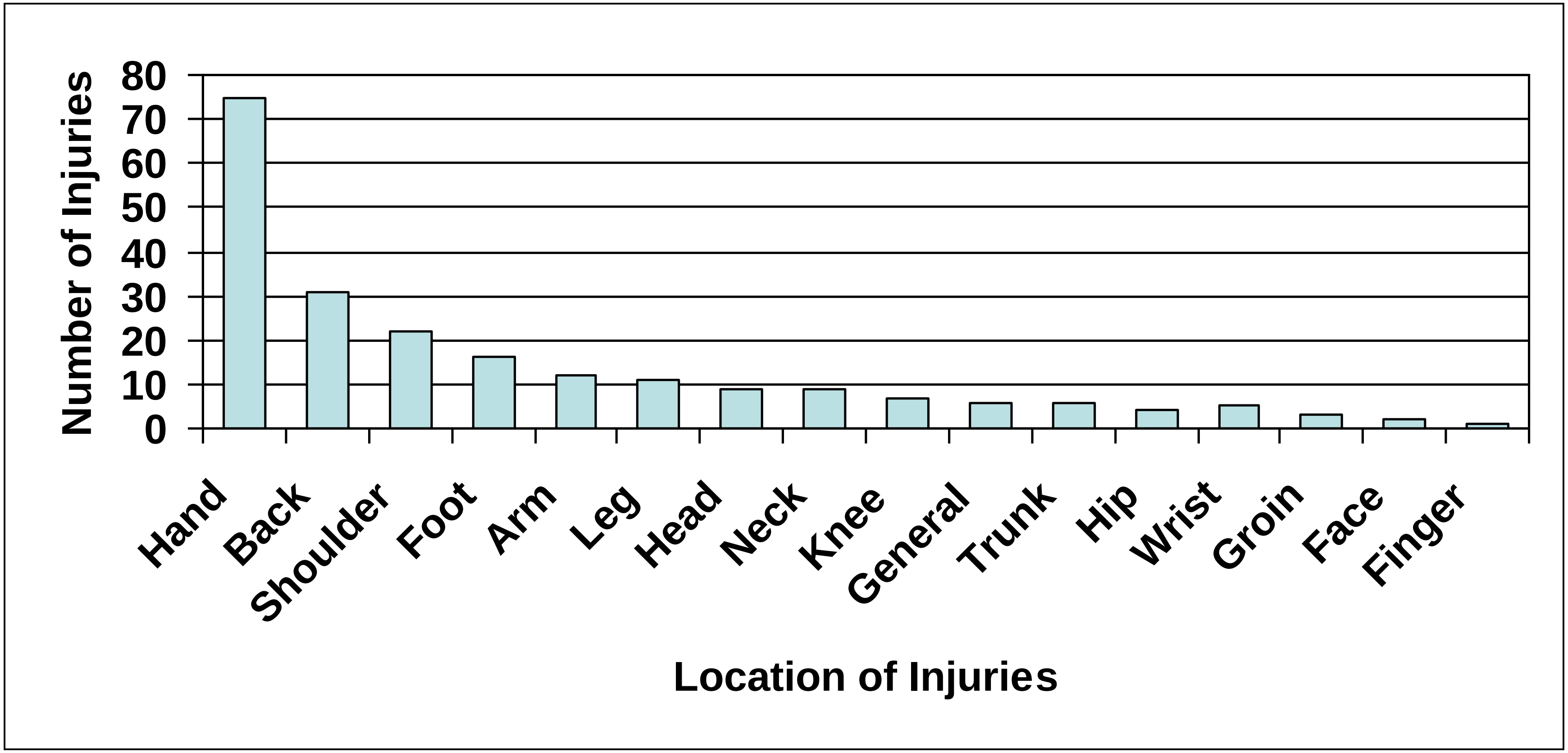
ISS Medical Capabilities Comparison



In-flight MSK US

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

Results


Number of Injuries
80
70
60
50
40
30
20
10
0
Hand
Back
Shoulder
Foot
Arm
Leg
Head
Neck
Knee
General
Trunk
Hip
Wrist
Groin
Face
Finger
Location of Injuries

Results

Photo courtesy of Drs. Sam Strauss and Jeff Jones, NASA-JSC

Photo courtesy of Dr. Joseph Dervay, NASA-JSC

EVA 32, ISS EXP 35/36, July, 2013

- EVA accounted for an incidence rate of 0.26 injuries per EVA.
  - EVA injuries occurred primarily in the hands and feet
  - These injuries may represent an exacerbation of pre-flight injury during training in the Neutral Buoyancy Laboratory
  - Shoulder SLAP lesion occurred during suit doffing after second EVA

In-flight MSK Conditions *cont'd…*

RESEARCH ARTICLE

Space Adaptation Back Pain: A Retrospective Study

Eric L. Kerstman, Richard A. Scheuring,
Matt G. Barnes, Tyson B. DeKorse, and Lynn G. Saile

Kerstman EL, Scheuring RA, Barnes MG, DeKorse TB, Saile LG. *Space adaptation back pain: a retrospective study.* Aviat Space Environ Med 2012; 83:1–6.

Introduction: Back pain is frequently reported by astronauts during the early phase of spaceflight as they adapt to microgravity. The epidemiology of space adaptation back pain has not been well defined. This study aims to develop a case definition of space adaptation back pain, determine its incidence, and assess the effectiveness of available treatments. ***Methods:*** Medical records from the Mercury, Apollo, Apollo-Soyuz Test Project (ASTP), Skylab, Mir, International Space Station (ISS), and Shuttle programs were reviewed. All episodes of in-flight back pain that met the criteria for space adaptation back pain were recorded. Pain characteristics, including intensity, location, and duration of the pain, were noted. The effectiveness of specific treatments also was recorded. ***Results:*** The incidence of space adaptation back pain among astronauts was determined to be 52% (382/728). Most of the affected astronauts reported mild pain (85%). Moderate pain was reported by 11% of the affected astronauts and severe pain was reported by 4% of the affected astronauts. The most effective treatments were fetal positioning (91%) and the use of analgesic medications and exercise (primarily treadmill and cycle ergometer), which were both 85% effective. ***Discussion:*** This retrospective study examines the epidemiology of space adaptation back pain. Space adaptation back pain is usually mild and self-limited. However, there is a risk of functional impairment and mission impact in cases of moderate or severe pain that do not respond to currently available treatments. Therefore, the development of preventive measures and more effective treatments should be pursued.

Keywords: crewmembers, NASA, zero gravity environment, spine, spinal lengthening, lumbar.

BACK PAIN IS frequently reported by astronauts in the early phase of spaceflight as they adapt to the microgravity environment (13,16). However, the epidemiology of space adaptation back pain (SABP) has not been well established. There have been few studies regarding SABP and the studies that have been performed are of limited scope (14). The exact incidence of SABP among astronauts is unknown. The pathophysiology and operational impacts of SABP also are largely unknown.

In 1991, a retrospective review of the medical records of 58 Shuttle crewmembers was conducted by the Flight Medicine Clinic at NASA Johnson Space Center to determine the incidence of back pain during spaceflight (16). Of the crewmembers, 68% had reported in-flight back pain. To obtain additional information regarding the nature of the reported in-flight back pain, pain questionnaires were completed by 19 Shuttle payload specialists, a subset of the original 58 Shuttle crewmembers. Of the 19 payload specialists, 14 (74%) reported in-flight back pain.

In 1994, a prospective bed rest study was performed on eight subjects to compare back pain and spinal lengthening during simulated microgravity (6° head-down tilt) with the same parameters during actual microgravity (4). The researchers concluded that back pain in actual and simulated microgravity may result from stretching of the spinal and/or paraspinal tissues until a new spinal length is reached. In 2009, a retrospective study evaluated in-flight musculoskeletal injuries occurring throughout the U.S. space program (9). However, cases of in-flight back pain related to space adaptation were excluded from that study.

The main objective of this study was to determine the incidence of SABP among astronauts in the U.S space program. A case definition of SABP was developed to facilitate the determination of this incidence. Additional objectives of this study were to delineate the nature and pattern of SABP, its treatment, and its operational impact. To accomplish these objectives, a comprehensive analysis of astronaut mission medical records was performed.

METHODS

All available mission records of astronauts in the U.S. space program from the NASA Johnson Space Center Flight Medicine Clinic were reviewed by the authors. These records included mission summaries, flight surgeon logs, preflight medical exams, postflight medical exams, and postflight medical debriefs. All missions of the Mercury, Gemini, Apollo, Apollo-Soyuz Test Project (ASTP), and Mir programs were included in the analysis. International Space Station (ISS) missions from Expedition 1 through Expedition 15 were included in the analysis. All Shuttle missions from STS-1 through STS-122 were reviewed, with the exception of STS-51L (Challenger) and STS-107 (Columbia). For most Shuttle missions, the postflight medical debriefs included a standardized back pain questionnaire. If available, Shuttle medical debriefs was reviewed via electronic data query. If electronic data were not available, paper

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This manuscript was received for review in July 2010. It was accepted for publication in September 2011.

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DOI: 10.3357/ASEM.2876.2012

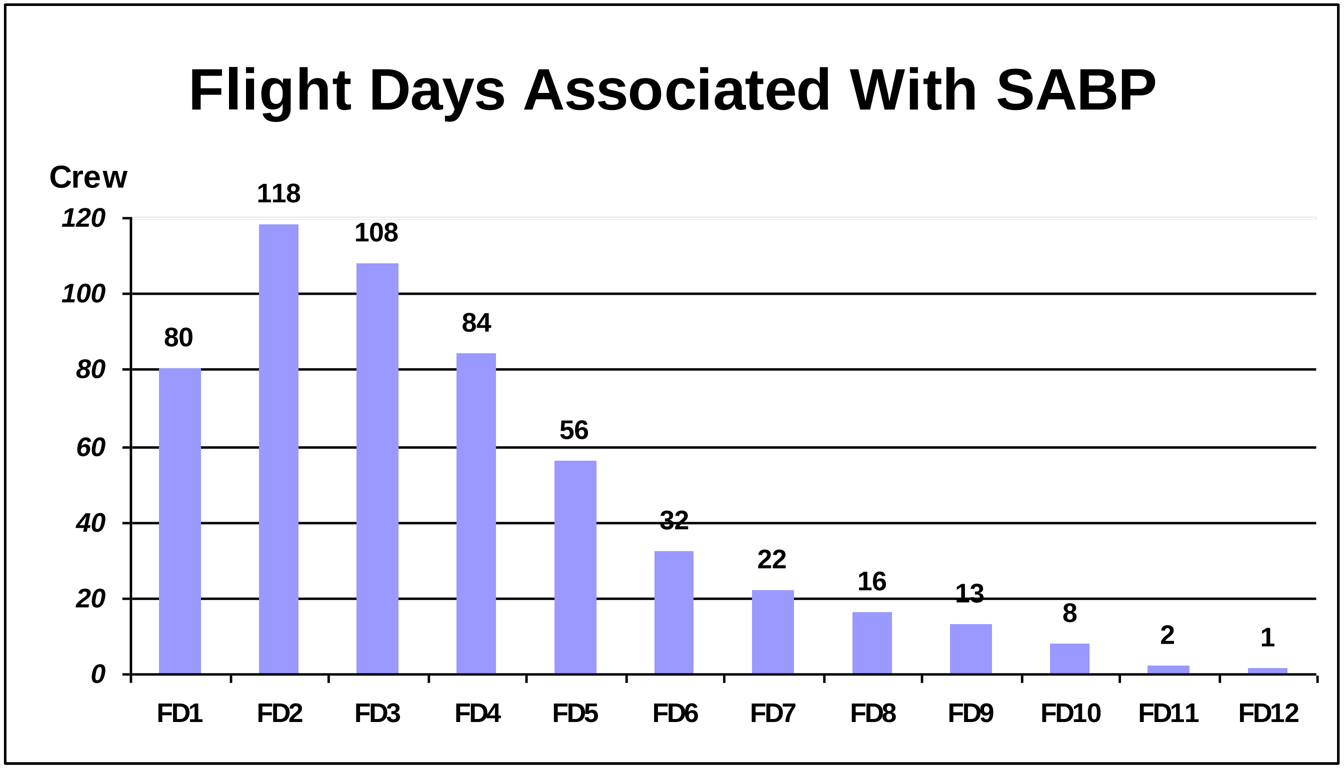
- Definition of SABP
  - Symptoms are not precipitated by an injury or related to prolonged recumbent sitting on the launch pad
  - Symptoms develop within the first 5 days of space flight
  - Multiple days of in-flight back pain were considered as one case

SABP Characteristics

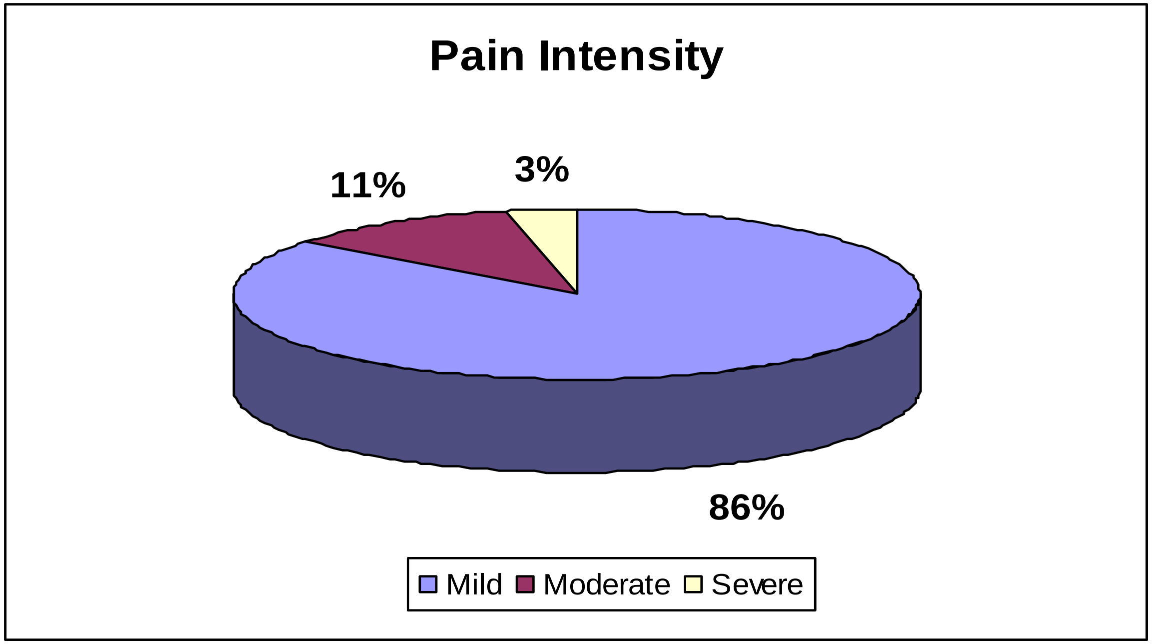
- Symptoms are usually mild to moderate
- Symptoms are usually localized to the lumbar region
- Symptoms are described as an ache or stiffness
- Symptoms typically occur during the sleep period
- Neurological symptoms (radicular pain, numbness, tingling) are absent
- Symptoms tend to improve or resolve with the use of bending the knees to the chest, stretching of the lumbar spine, or anti-inflammatory medication

SABP & Flight Days

SABP is present in the early phase of spaceflight, with a peak prevalence on FD 2 and none reported after FD12



SABP Intensity

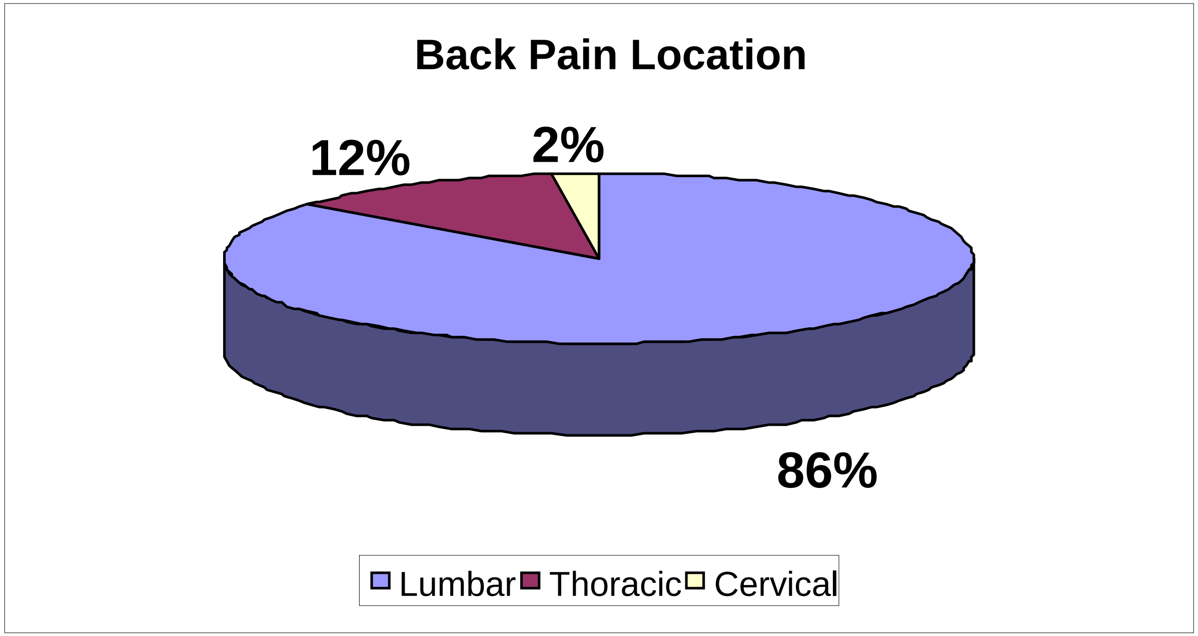


Mild pain 86%

Moderate pain 11%

Severe pain 3%

SABP Location

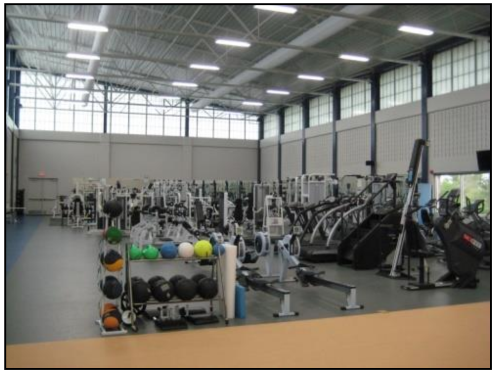


Lumbar	**86%**
Thoracic	**12%**
Cervical	**2%**

Conclusions

- The incidence of SABP has been determined to be 53% 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

Post-flight reconditioning



- Dynamic stretching and warm-up: R+0d
- Mobialanception: R+0d
- Medicine ball: R+0d
- Ladder and cone drills: R+7d
- Jumping drills: R+21d
- Core exercises: R+1d
- Static stretching: R+0d

Physiological Issues in Partial Gravity*

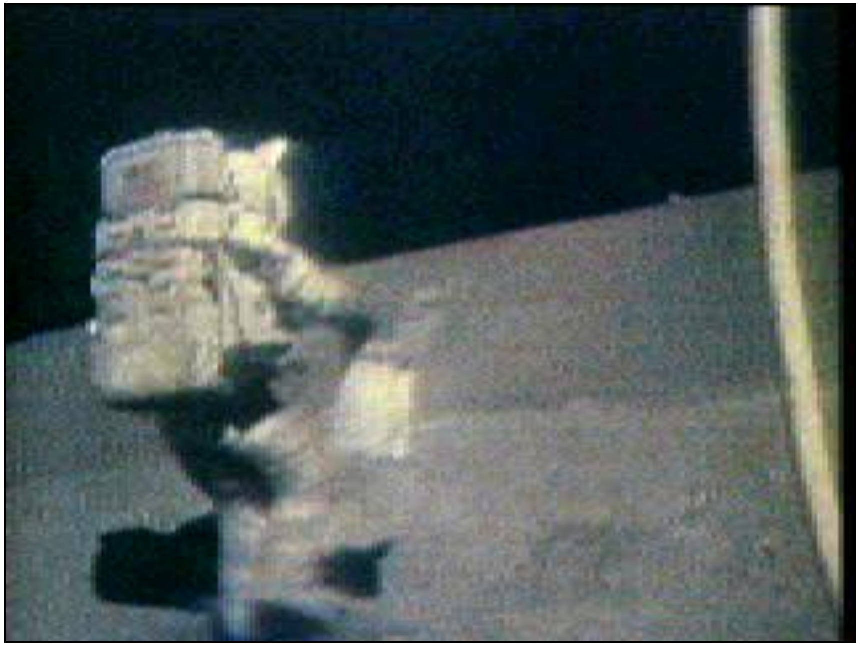
- Apollo lunar crews adapted quickly to the 1/6g environment
  - Initial unsteady gait related to EVA suit CG issues ***not*** neurovestibular dysfunction
  - Forearm and upper extremity fatigue attributed to glove design
  - Inadequate sleep, dietary caloric intake experienced by most crewmembers
  - Other physiologic function (cardiovascular, bone) unknown

G. Cernan, H. Schmitt, Apollo 17 Video courtesy of NASA

***Scheuring RA**, Davis, JR, et. al. The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations. Acta Astronautica, 63 (2008); 980 – 987.

Lunar MSK Conditions

- Apollo Lunar Surface Musculoskeletal Events or Minor Trauma
  - 9 Events were reported on the lunar surface related to EVA
    - 5 events located in the hand
    - 2 events occurred in the wrist
    - 1 event resulted in shoulder strain after EVA 2/3
    - 1 event described as general muscle fatigue while covering large distances by foot on the lunar surface



H. Schmitt, Apollo 17 Video courtesy of NASA

Lunar MSK Conditions *cont'd…*

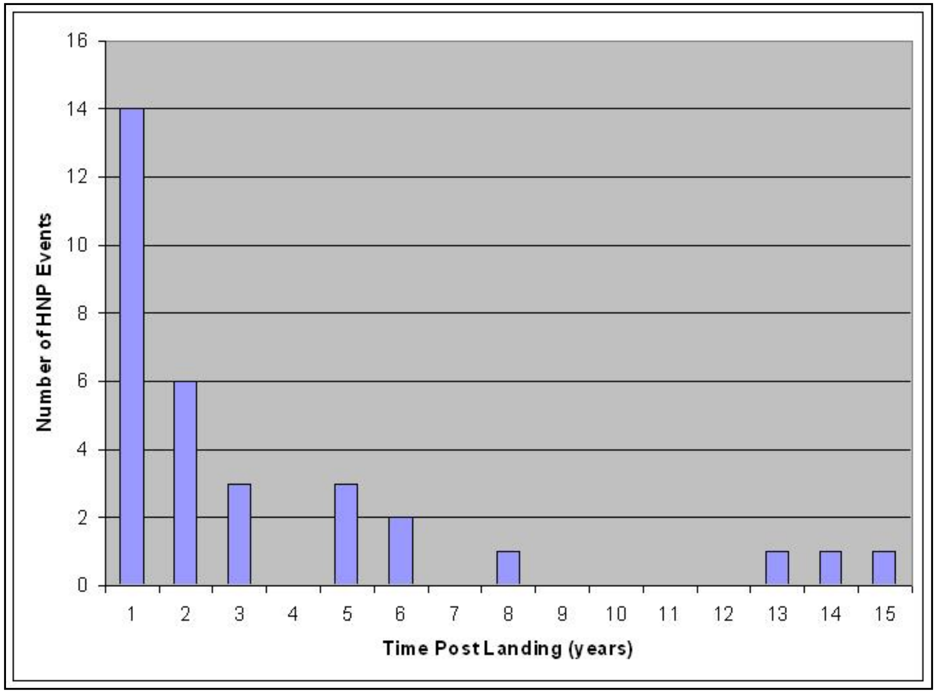
G. Cernan, H. Schmitt, Apollo 17 Video courtesy of NASA

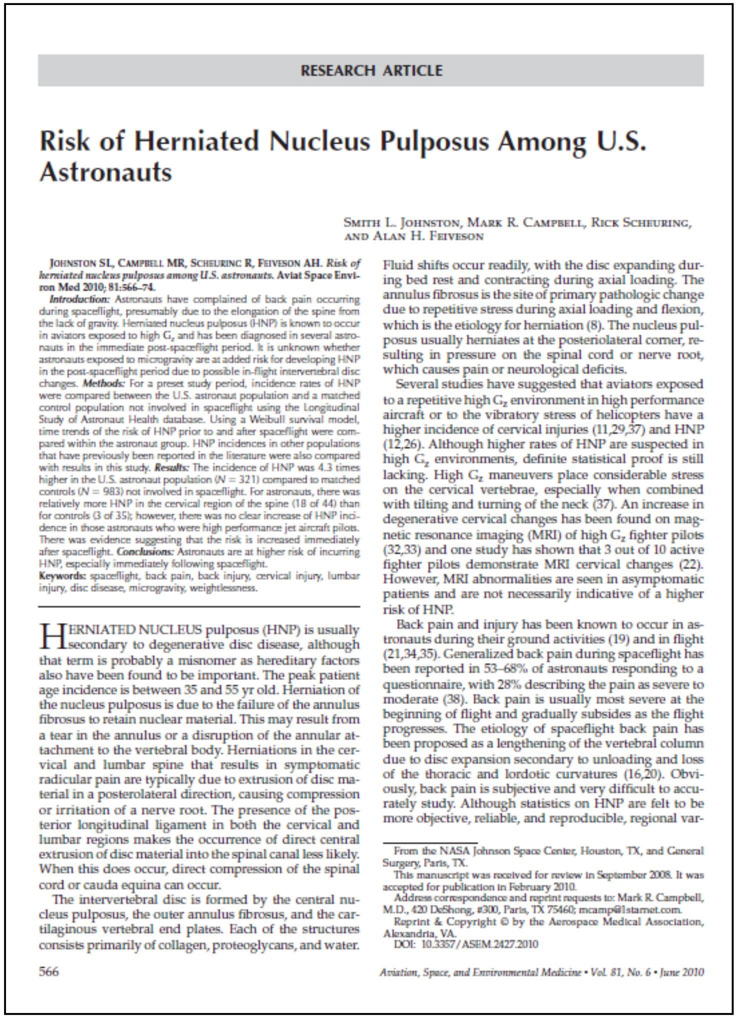
- Apollo Lunar Surface Musculoskeletal Events or Minor Trauma
  - MCP, distal phalanx pain, swelling and abrasions after lunar 3/3 EVA
    - "*Completing a subsequent EVA would have been very difficult on account of how sore and swollen my hands were*"
  - 2 events occurred in the wrist
    - Wrist laceration due to suit wrist ring cutting into skin
    - Wrist soreness where suit sleeve repetitively rubbed on surface
  - 1 event resulted in shoulder strain after EVA 2/3
    - Crewmember injured shoulder during surface drilling activity
      - Required large doses of aspirin to relieve pain

Post-flight MSK Conditions

- Herniated nucleus pulposus (HNP)
- Lumbar back pain
- Soyuz landing injuries

Post-flight MSK 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-

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

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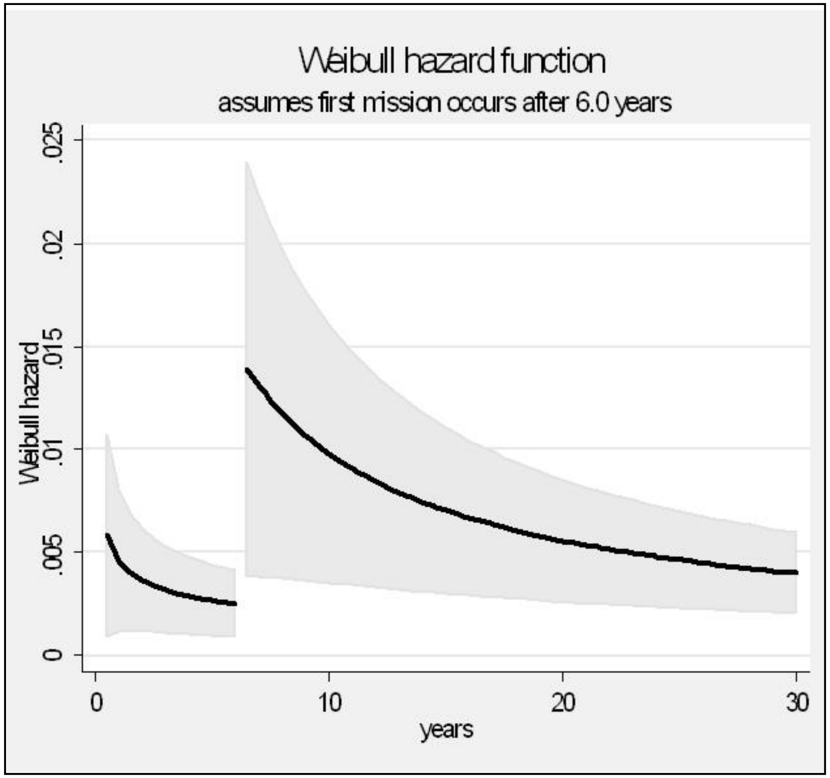
DOI: 10.3357/ASEM.2427.2010

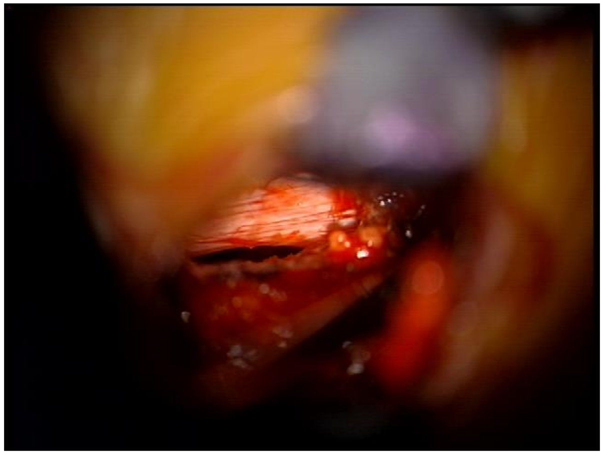
Results



- 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

Intraoperative Observation

- Mechanism of nucleosis pulposus herniation

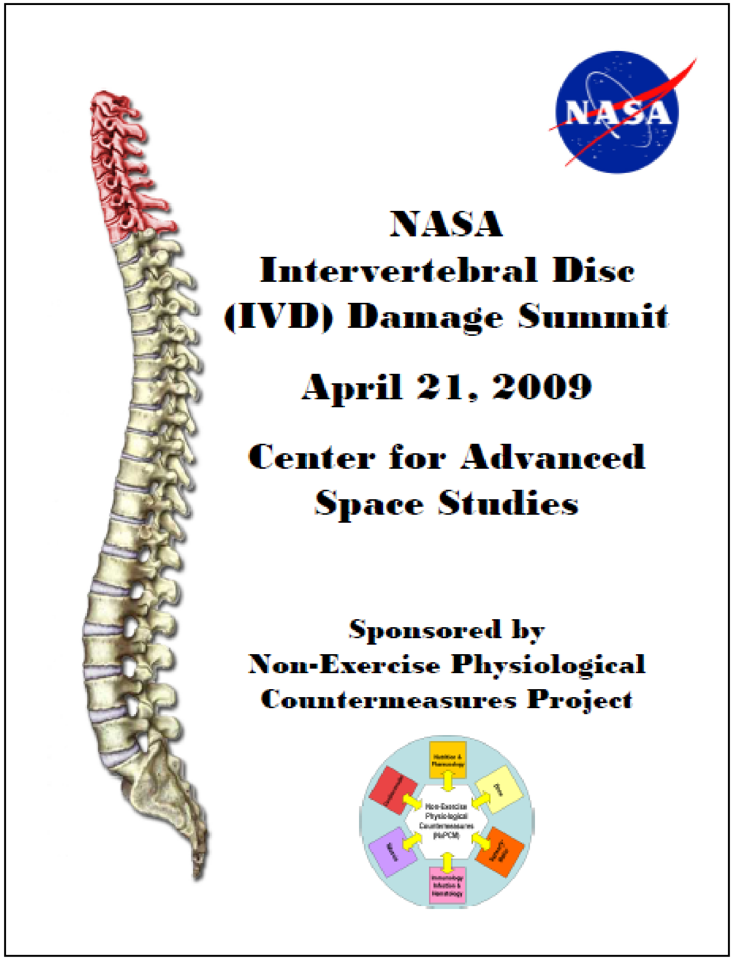


Conclusions

- 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

Recommendations of the NASA IVD Summit (May 2009)

- Minimize axial loading first 48 hrs post-landing
- Minimal and protected ambulation first week post-landing
- Pre-flight neck muscle strengthening is of only speculative benefit
- In-flight countermeasures would likely not be effective with our current capability (need sustained axial loading)



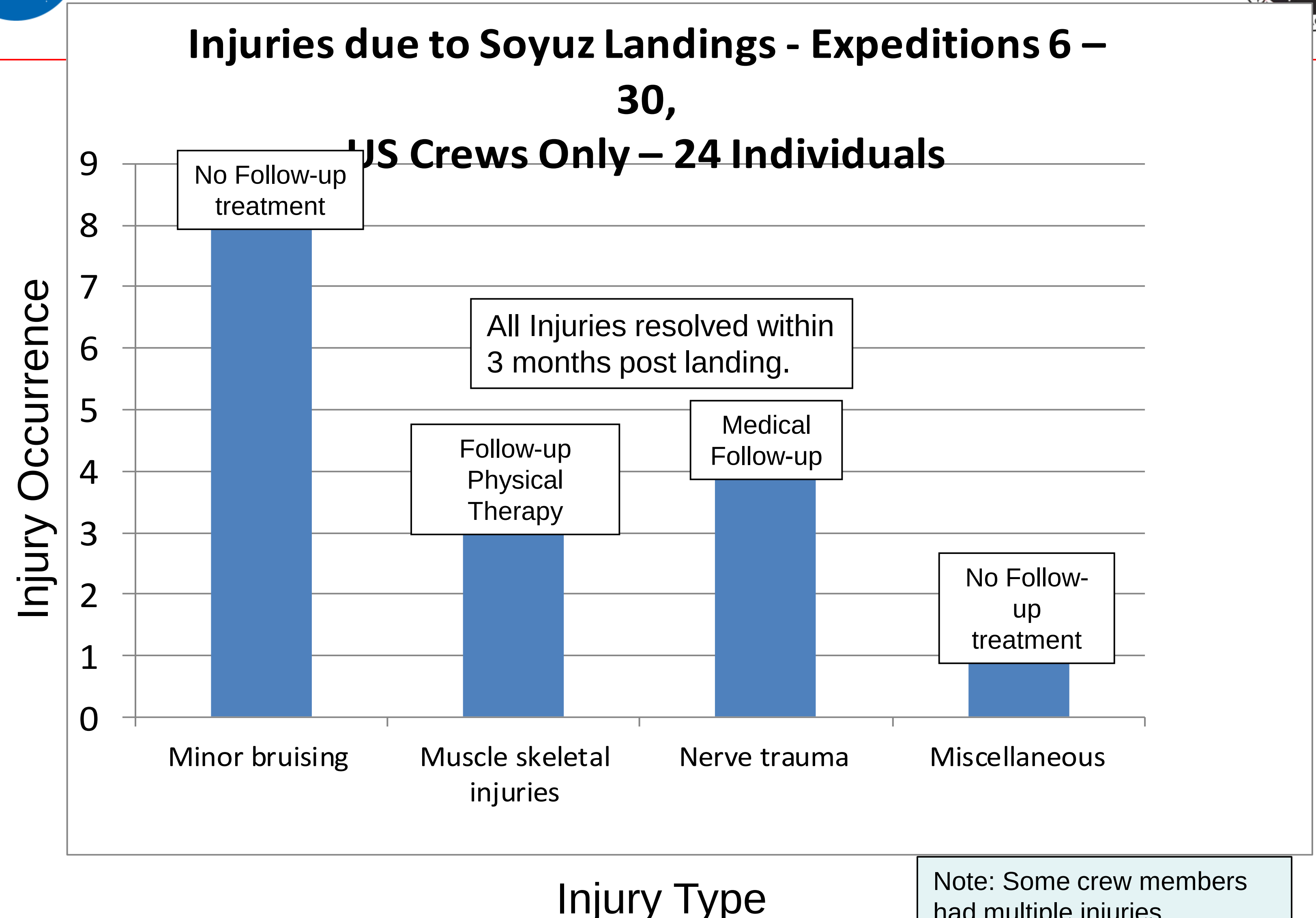
USOS Soyuz Injuries (continued)

The following injuries were reported in the Electronic Medical Records and/or in the Space Medicine Operational Team tags.
Note : Some crew have experienced more than on injury. 9 of 24 crew have experienced at least one injury.

- **4 cases of nerve trauma requiring follow-up**
  - Mild left radial nerve distribution pattern reduction without evidence of acute or chronic denervation
  - Muscle fasciculation ("shivering" of lower extremities) lasting for approximately 2 hours
  - Meralgia paresthetica, i.e. Lateral femoral cutaneous nerve (LFCN) entrapment*

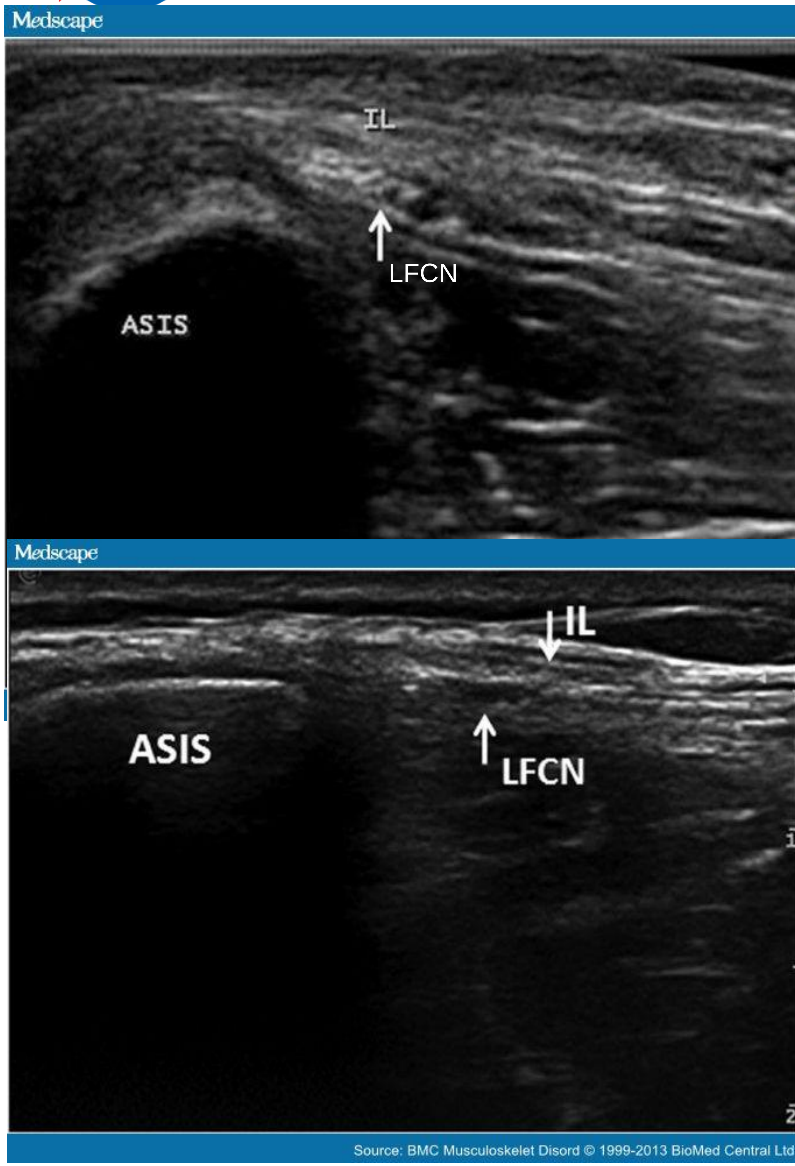
- **1 case of retinal ischemia** – requiring medical follow-up – no treatment
  - Retinal ischemia, right eye – vision not affected

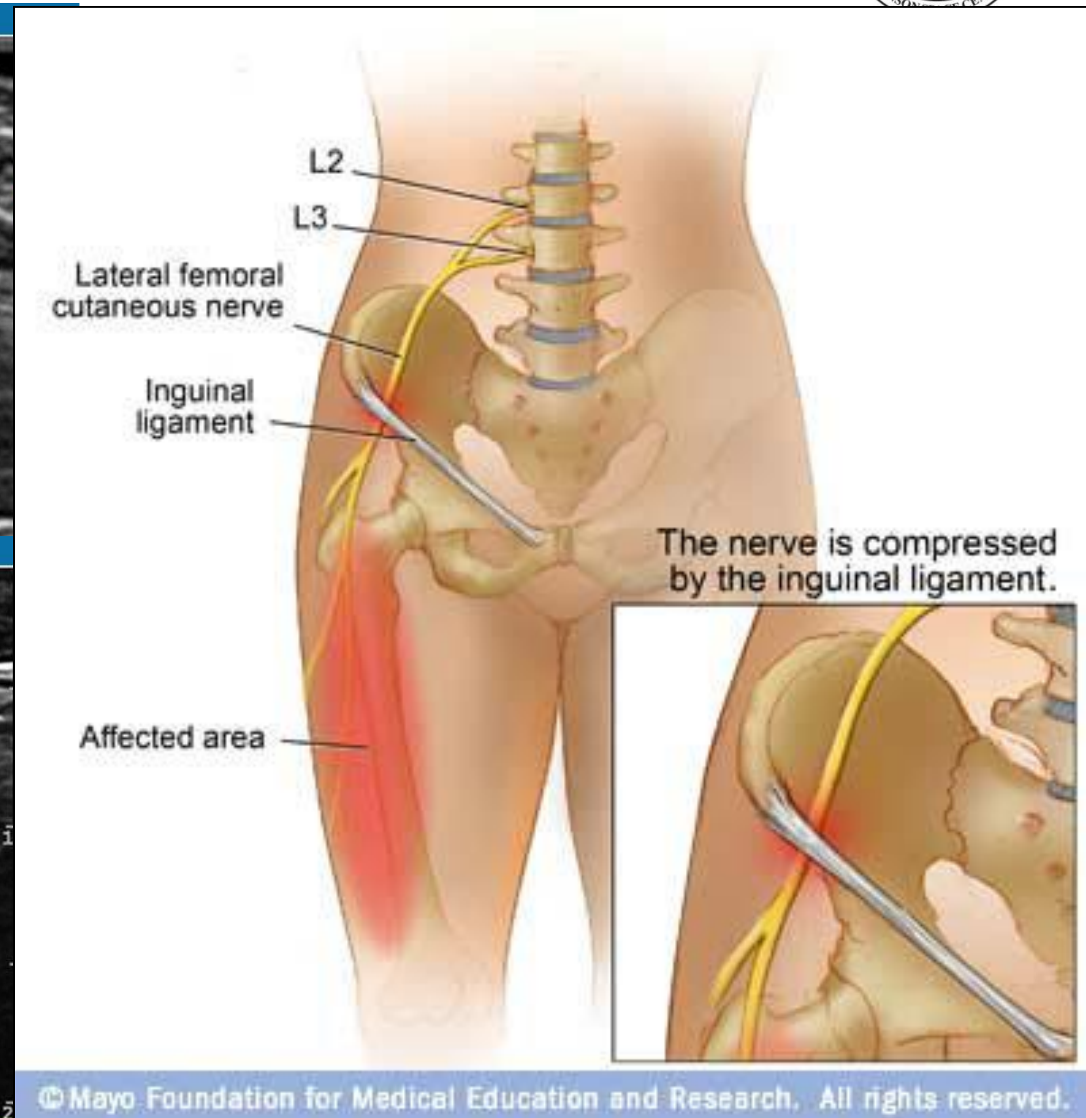
Soyuz Injuries – Summary Chart



Note: Some crew members had multiple injuries.
9 of 24 experienced an injury.

Meralgia Paresthetica





Future Considerations

Thank You

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