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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Bethesda, MD
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
• First study to look at terrestrial-based musculoskeletal injuries in US astronauts

• Genesis of the Astronaut Strength, Conditioning and Rehabilitation (ASCR) specialists

Terrestrial experience

Musculoskeletal Injury Review in the U.S. Space Program

Richard T. Jennings, M.D., M.S., and James P. Bagian, M.D.

First study to look at terrestrial-based musculoskeletal injuries in US astronauts

Genesis of the Astronaut Strength, Conditioning and Rehabilitation (ASCR) specialists
Fractures and physical activities associated with fractures

<table>
<thead>
<tr>
<th>Fractures</th>
<th>Physical Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ribs 5</td>
<td>Running 7</td>
</tr>
<tr>
<td>Tibia 4</td>
<td>Snow Skiing 4</td>
</tr>
<tr>
<td>Fingers 3</td>
<td>Basketball 2</td>
</tr>
<tr>
<td>Toes 3</td>
<td>MVA 2 (1 motorcycle)</td>
</tr>
<tr>
<td>Metatarsal 2</td>
<td>Household 2</td>
</tr>
<tr>
<td>Radius 2</td>
<td>Softball 1</td>
</tr>
<tr>
<td>Medial Malleolus 1</td>
<td>Water Skiing 1</td>
</tr>
<tr>
<td>Talus 1</td>
<td>Horse 1</td>
</tr>
<tr>
<td>Fibula 1</td>
<td>Soccer 1</td>
</tr>
<tr>
<td>Metacarpal 1</td>
<td>Training 1</td>
</tr>
<tr>
<td>Os calcis 1</td>
<td>Other than Athletic 4</td>
</tr>
<tr>
<td>Humerus 1</td>
<td></td>
</tr>
<tr>
<td>Face 1</td>
<td></td>
</tr>
</tbody>
</table>

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

Orthopedic surgeries in US astronauts

1Jennings RT, Bagian JP. Aviation, Space, and Environmental Medicine; Vol 67, No. 8 9 August 1996
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
• 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…
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 Mobility Unit (EMU) Training Injuries

• **Shoulder**
  – rotator cuff tendonitis, SASD bursitis, LHBT tenosynovitis, SLAP lesion, impingement syndrome, anterior impingement (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 SAX, and abnormal left EPL.
- Normal right CET in LAX, and abnormal left CET.

3rd dorsal (extensor) compartment (EPL)
Common extensor tendon (CET) tenosynovitis
Number of Reported Shoulder Injuries & Surgeries by Year

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

• Remove lower arm assembly to prevent doff/don injuries
  – Feedback has generally been favorable for decreasing shoulder/elbow stresses
  – Not performed on -orbit
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.
• 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

- 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

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**NASA EVA Functional Capacity Evaluation (FCE) and Work Hardening Program Development Effort Summary**

16 Sep 2013

- **CB**: Sarah Aune, Dan Borback, Tracy Caldwell-Dyson, Amy Ellison, Pat Ferrarini, Nicole Stott, Peg Whitson, Susan Williams
- **DX**: Jordan Lindsey, Paul Dunn
- **SD**: Jamie Chastain, Joe Devay, David Hvam, Smith Johnston, Eric Kerstman, Jim Locke, Bruce Mischke, Rich Schramm, Bill Towner
- **SK**: Lori Elmore, Jamie Guinot
- **TA**: Jessica McDonald

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I. **Definition**

a. **Functional Capacity Evaluation (FCE)**
   - 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)**
   - 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**

   - i. Develop an NBL functional capacity evaluation (FCE) for selection and operational evaluation by the ASCRs.
   - ii. Develop a supervised mandatory exercise program and angular stabilization training program to be conducted within 6 months of initial NBL return, 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 for the 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.
<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>WARM UP EXERCISE</td>
<td>WARM UP EXERCISE</td>
<td>WARM UP EXERCISE</td>
<td>WARM UP EXERCISE</td>
<td>HIGH VOLUME ENDURANCE</td>
</tr>
<tr>
<td>20-15-10</td>
<td>3 Rounds</td>
<td>4 Rounds</td>
<td>3 Rounds</td>
<td>Grind</td>
</tr>
<tr>
<td>Pull Ups</td>
<td>15 Thrusters</td>
<td>25 Air Squats</td>
<td>10 Push Press</td>
<td>Every 30 secs</td>
</tr>
<tr>
<td>Dips</td>
<td>15 Push ups</td>
<td>15 Pushups</td>
<td>5 Knee to Elbow</td>
<td>2 burpees + 5 Dips for 10 rounds</td>
</tr>
<tr>
<td>Walking Lunges (on 15+1)</td>
<td></td>
<td>10 Half Moons (5 each side)</td>
<td>Then</td>
<td></td>
</tr>
<tr>
<td>STRENGTH &amp; SKILL</td>
<td>ENERGY SYSTEM DEVELOPMENT</td>
<td>STRENGTH &amp; SKILL</td>
<td>ENERGY SYSTEM DEVELOPMENT</td>
<td></td>
</tr>
<tr>
<td>Then Super Set: Deadlifts (Heavy) &amp; Hammer Row: 3 x 12, 4th set AMAP Presses</td>
<td>Aerobic System</td>
<td>Then Super Set: Dumbbell Bench Press &amp; Shrugs 3 x 12, 4th set AMAP</td>
<td>ATP-CP (Phosphagen System)</td>
<td>10 Rounds</td>
</tr>
<tr>
<td>FINISHER WORKOUT</td>
<td></td>
<td>FINISHER WORKOUT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As Many Rounds as Possible in 20 Minutes of:</td>
<td></td>
<td>Row 800</td>
<td>10 Pushups</td>
<td></td>
</tr>
<tr>
<td>10 Push Ups</td>
<td></td>
<td>21 Renegade Man Makers</td>
<td>SHOULDER MAINTENANCE</td>
<td></td>
</tr>
<tr>
<td>10 Front Squats</td>
<td></td>
<td></td>
<td>10 rounds</td>
<td></td>
</tr>
<tr>
<td>10 Weight Sit Ups</td>
<td></td>
<td></td>
<td>Run or row 100M</td>
<td></td>
</tr>
<tr>
<td>CORE DEVELOPMENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2x10: Shoulder Slides w/ towel, 2x10: Plank Shoulder Taps (1 tap each side = 1) 2x10: Front Plank hip dips (1 tap each side = 0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Renegade Man Makers</td>
<td></td>
<td></td>
<td>Hitchiker w/ DBs 5 lbs max</td>
<td></td>
</tr>
<tr>
<td>Rengacade ManMakers are DB burpees (with no jump) to a Push-Up</td>
<td>2x10: Wood Chopper/Hay Baler w/ med ball</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 x 30-45 sec holds Reverse Plank</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 x Plank Walks 3 steps forward, 3 steps backwards</td>
<td></td>
</tr>
<tr>
<td>10 MINUTES OF STRETCHING / FOAM ROLLER</td>
<td>10 MINUTES OF STRETCHING / FOAM ROLLER</td>
<td>10 MINUTES OF STRETCHING / FOAM ROLLER</td>
<td>10 MINUTES OF STRETCHING / FOAM ROLLER</td>
<td>10 MINUTES OF STRETCHING / FOAM ROLLER</td>
</tr>
</tbody>
</table>
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
<table>
<thead>
<tr>
<th>REGION</th>
<th>TYPE OF INJURY</th>
<th># OF CASES</th>
<th>SURGERY?</th>
<th>RTD</th>
<th>AMB WAIVER REQUIRED?</th>
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</thead>
<tbody>
<tr>
<td>Shoulder</td>
<td>Rotator cuff tear-full thickness</td>
<td>4</td>
<td>Yes</td>
<td>T-38, NBL six months, SF one year</td>
<td>No</td>
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<tr>
<td></td>
<td>Rotator cuff tear-partial thickness</td>
<td>3</td>
<td>No</td>
<td>T-38, NBL six weeks, SF three months</td>
<td>No</td>
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<tr>
<td></td>
<td>SLAP lesion Grade 2-4</td>
<td>3</td>
<td>Yes</td>
<td>T-38 three months, NBL six months, SF one year</td>
<td>No</td>
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<tr>
<td></td>
<td>SLAP lesion Grade 1</td>
<td>2</td>
<td>No</td>
<td>T-38, NBL, SF three months</td>
<td>No</td>
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<tr>
<td></td>
<td>Biceps tendon tear</td>
<td>2</td>
<td>Yes</td>
<td>T-38, NBL three months, SF six months</td>
<td>No</td>
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<tr>
<td></td>
<td>Acromioclavicular joint</td>
<td>3</td>
<td>Yes</td>
<td>T-38, NBL three months, SF six months</td>
<td>No</td>
</tr>
<tr>
<td>Knee</td>
<td>Medial Collateral Ligament</td>
<td>6</td>
<td>No</td>
<td>SF six weeks</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Meniscus w/o repair</td>
<td>1</td>
<td>No</td>
<td>T-38, NBL, SF six weeks</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Anterior Cruciate Ligament</td>
<td>2</td>
<td>Yes</td>
<td>T-38, NBL six months, SF one year</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Anterior Cruciate Ligament</td>
<td>1</td>
<td>No</td>
<td>T-38, NBL, SF six weeks</td>
<td>No</td>
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<tr>
<td></td>
<td>Osteoarthritis w/o replacement</td>
<td>3</td>
<td>Yes</td>
<td>T-38, NBL, SF six weeks</td>
<td>No</td>
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<tr>
<td></td>
<td>Osteoarthritis w/ replacement</td>
<td>2</td>
<td>Yes</td>
<td>T-38, NBL six months, SDSF one year</td>
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<tr>
<td>Knee</td>
<td>Medial, Lateral Meniscus tear</td>
<td>6</td>
<td>Yes</td>
<td>T-38 three weeks, NBL six weeks, SF*</td>
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<tr>
<td></td>
<td>Meniscus w/ repair</td>
<td>1</td>
<td>No</td>
<td>T-38, NBL, SF six weeks</td>
<td>No</td>
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<tr>
<td>Lumbar Spine</td>
<td>HNP w/ radiculopathy ACDF</td>
<td>4</td>
<td>Yes</td>
<td>T-38, NBL six months, SF one year</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>HNP w/o radiculopathy</td>
<td>11</td>
<td>No</td>
<td>T-38, NBL six weeks, SF three months</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Degenerative disc disease</td>
<td>3</td>
<td>No</td>
<td>T-38, NBL six weeks, SF three months</td>
<td>No</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>HNP w/ radiculopathy</td>
<td>1</td>
<td>Yes</td>
<td>T-38, NBL, SF six weeks</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>HNP w/o radiculopathy</td>
<td>2</td>
<td>No</td>
<td>T-38, NBL, SF six weeks</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Degenerative disc disease</td>
<td>3</td>
<td>No</td>
<td>T-38, NBL six weeks, SF three months</td>
<td>No</td>
</tr>
</tbody>
</table>
In-flight MSK Conditions

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

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

---

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

**RESEARCH ARTICLE**

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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

Location of Injuries

Number of Injuries

Hand  Back  Shoulder  Foot  Arm  Leg  Head  Neck  Knee  General  Trunk  Hip  Wrist  Groin  Face  Finger

20-Jun-17
Results

- 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

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
In-flight MSK Conditions cont’d…

• 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

From The University of Texas Medical Branch, Galveston, TX; NASA Johnson Space Center, Houston, TX; Baylor College of Medicine, Houston, TX; Wright-Patterson AFB, Dayton, OH; and Brigham and Women’s Hospital, Boston, MA. This manuscript was revised for review in July 2003. It was accepted for publication in September 2003.

Abbreviations and Correspondence to Eric L. Kerstein, M.D., Wright-Patterson AFB, Dayton, OH 45433; kersteinw@wpaib.af.mil.
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.

**Flight Days Associated With SABP**

<table>
<thead>
<tr>
<th>Flight Day</th>
<th>Crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>FD1</td>
<td>80</td>
</tr>
<tr>
<td>FD2</td>
<td>118</td>
</tr>
<tr>
<td>FD3</td>
<td>108</td>
</tr>
<tr>
<td>FD4</td>
<td>84</td>
</tr>
<tr>
<td>FD5</td>
<td>56</td>
</tr>
<tr>
<td>FD6</td>
<td>32</td>
</tr>
<tr>
<td>FD7</td>
<td>22</td>
</tr>
<tr>
<td>FD8</td>
<td>16</td>
</tr>
<tr>
<td>FD9</td>
<td>13</td>
</tr>
<tr>
<td>FD10</td>
<td>8</td>
</tr>
<tr>
<td>FD11</td>
<td>2</td>
</tr>
<tr>
<td>FD12</td>
<td>1</td>
</tr>
</tbody>
</table>
SABP Intensity

Mild pain: 86%
Moderate pain: 11%
Severe pain: 3%
SABP Location

Back Pain Location

- Lumbar: 86%
- Thoracic: 12%
- Cervical: 2%

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

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
• 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

Risk of Herniated Nucleus Pulposus Among U.S. Astronauts

Smith J. Johnston, Mark R. Campbell, Richard Schneider, and Alan L. Pergolizzi

Fluid shifts occur rapidly, with the disc expanding during bed rest and continuing during normal landing. The annulus fibrosus is the most primary pathologic change due to repetitive stresses during axial flexion and retraction, which is the strategy for herniation. The nucleus pulposus usually herniates at the posterosuperior corner, resulting in pressure on the spinal cord or nerve root, which causes pares to neurological deficits.

Several studies have suggested that actions expeditious to a repetitive high Gx environment in high performance aircraft, or in the vibratory space of helicopters have a higher incidence of cervical injuries (13,15,17) and HNP (15,20). Although higher rates of HNP are suspected in high Gx environments, definite causal factors for this are lacking. High Gx maneuvers place considerable stress on the cervical vertebra, especially when used in combination with blinding and turning of the neck (25). An increase in degenerative cervical changes has been noted on magnetic resonance imaging (MRI) of high Gx fighter pilots (22,23). One study has shown that 4 out of 10 active high Gx pilots demonstrated 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 found to occur in astronauts during crewed spaceflights (10) and in flight (23,34,35). Generalized back pain during spaceflight has been reported in 53-60% of astronauts returning to a questionnaire, with 22% describing the pain as severe to moderate (23) back pain is usually most severe at the beginning of flight and gradually subsides during the flight programme. The etiology of spaceflight back pain has been posited as a lengthening of the vertebral column due to disc expansion secondary to unloading and loss of the intrinsic and lordotic curvatures (16,22). Usually, back pain is subjective and very difficult to accurately study, although symptoms on HNP are felt to be more objective, reliable, and reproducible, regional variation.

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Herniated Nucleus Pulposus (HNP) is usually a consequence of degenerative disc disease, although this term is probably misnomer as auxiliary factors have also been found to be important. The peak prevalence incidence is between 35 and 55 years 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, a disruption of the annular architecture to the vertebral body, herniation in the central and annular space that results in symmetrical radiculopathy or typically due to erosion or disc material in a posterosuperior direction, causing compression or irritation of a nerve root. The presence of the posterior longitudinal ligament in both the cervical and lumbar region makes the occurrence of direct central extension 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 these structures consists primarily of collagen, proteoglycans, and water.


RESEARCH ARTICLE

Number of HNP Events

Time Post Landing (years)

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

16 14 12 10 8 6 4 2 0

20-Jun-17
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)
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 one 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

Injuries due to Soyuz Landings - Expeditions 6 – 30,
US Crews Only – 24 Individuals

- Minor bruising: 9 occurrences
- Muscle skeletal injuries: 3 occurrences
- Nerve trauma: 2 occurrences
- Miscellaneous injuries: 1 occurrence

All Injuries resolved within 3 months post landing.

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

LFCN

IL

ASIS

L2

L3

Inguinal ligament

Lateral femoral cutaneous nerve

Affected area

The nerve is compressed by the inguinal ligament.
Future Considerations
Thank You
Injuries to Crewmembers during Nominal Operation of Soyuz Landing Systems Bibliography


