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

• Genesis of the Astronaut Strength, Conditioning and Rehabilitation (ASCR) specialists
# Terrestrial MSK Injury in US Astronauts

<table>
<thead>
<tr>
<th>Fractures and Physical Activities Associated with Fractures</th>
<th>Orthopedic Surgeries in US Astronauts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ribs 5</td>
<td>Knee 19</td>
</tr>
<tr>
<td>Tibia 4</td>
<td>Neck and low back 8</td>
</tr>
<tr>
<td>Fingers 3</td>
<td>Shoulder 2</td>
</tr>
<tr>
<td>Toes 3</td>
<td>Ankle 1</td>
</tr>
<tr>
<td>Metatarsal 2</td>
<td>Foot 1</td>
</tr>
<tr>
<td>Radius 2</td>
<td></td>
</tr>
<tr>
<td>Medial Malleolus 1</td>
<td></td>
</tr>
<tr>
<td>Talus 1</td>
<td></td>
</tr>
<tr>
<td>Fibula 1</td>
<td></td>
</tr>
<tr>
<td>Metacarpal 1</td>
<td></td>
</tr>
<tr>
<td>Os calcis 1</td>
<td></td>
</tr>
<tr>
<td>Humerus 1</td>
<td></td>
</tr>
<tr>
<td>Face 1</td>
<td></td>
</tr>
<tr>
<td>Running 7</td>
<td></td>
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<tr>
<td>Snow Skiing 4</td>
<td></td>
</tr>
<tr>
<td>Basketball 2</td>
<td></td>
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<tr>
<td>MVA 2 (1 motorcycle)</td>
<td></td>
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<tr>
<td>Household 2</td>
<td></td>
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<tr>
<td>Softball 1</td>
<td></td>
</tr>
<tr>
<td>Water Skiing 1</td>
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<td>Horse 1</td>
<td></td>
</tr>
<tr>
<td>Soccer 1</td>
<td></td>
</tr>
<tr>
<td>Training 1</td>
<td></td>
</tr>
<tr>
<td>Other than Athletic 4</td>
<td></td>
</tr>
</tbody>
</table>

1Jennings RT, Bagian JP. *Aviation, Space, and Environmental Medicine; Vol 67, No. 8* 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.
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) tenosynovitis
• Common extensor tendon (CET) tendinosis
Number of Reported Shoulder Injuries & Surgeries by Year

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

MSK Injury Prevention Program initiated

Shuttle Program Ends

9-Sep-18  UCSD Ortho Grand Rounds
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
• 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**

<table>
<thead>
<tr>
<th>MONDAY</th>
<th>TUESDAY</th>
<th>WEDNESDAY</th>
<th>THURSDAY</th>
<th>FRIDAY</th>
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<tr>
<td><strong>WARM UP EXERCISE</strong></td>
<td><strong>WARM UP EXERCISE</strong></td>
<td><strong>WARM UP EXERCISE</strong></td>
<td><strong>WARM UP EXERCISE</strong></td>
<td>HIGH VOLUME ENDURANCE</td>
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<tr>
<td>20-15-10</td>
<td>3 Rounds</td>
<td>4 Rounds</td>
<td>3 Rounds</td>
<td>Grind</td>
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<tr>
<td>Pull Ups</td>
<td>15 Thrusters</td>
<td>25 Air Squats</td>
<td>10 Push Press</td>
<td>Every 30 secs</td>
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<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>
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<tr>
<td>Walking Lunges (on 15+1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STRENGTH & SKILL**

Then Super Set: Deadlifts (Heavy) & Hammer Row: 3 x 12, 4th set AMAP Presses

**ENERGY SYSTEM DEVELOPMENT**

Aerobic System

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%.

**STRENGTH & SKILL**

Then Super Set: Dumbbell Bench Press & Shrugs x 12, 4th set AMAP

**ENERGY SYSTEM DEVELOPMENT**

ATP-CP (Phosphagen System)

Then 10 Rounds of Jacobs Ladder with weighted vest (1 min fast climb, 20 secs rest)

**FINISHER WORKOUT**

As Many Rounds as Possible in 20 Minutes of:

- Row 800
- 1 Lap Framers Walk

- 21 Renegade Man Makers
- 10 Push Ups
- 10 Front Squats
- 10 Weight Sit Ups

**SHOULDER MAINTENANCE**

Row 400

- 2 Rounds of 10
- Run or row 100M

2x10: 3 Way Scarecrow (palms up, palms in and palms out) 5 lbs DB max

15 Renegade Man Makers

2x10: Kneeling "Bottoms Up" Kettlebell Press (10 each arm)

Row 200

Band Pull Apart Stayin’ Alive

- 1 to 1 ratio (rest)

Core Development

9 Renegade Man Makers

Rengacade ManMakers are DB burpees (with no jump) to a Push-Up

**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**

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**10 MINUTES OF STRETCHING / FOAM ROLLER**
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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<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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<td>Rotator cuff tear-partial thickness</td>
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<td>T-38, NBL six weeks, SF three months</td>
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<td></td>
<td>SLAP lesion Grade 2-4</td>
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<td>Biceps tendon tear</td>
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<td>Acromioclavicular joint</td>
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<td>Medial Collateral Ligament</td>
<td>6</td>
<td>No</td>
<td>SF six weeks</td>
<td>No</td>
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<tr>
<td>Knee</td>
<td>Medial, Lateral Meniscus tear</td>
<td>6</td>
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<td>Meniscus w/o repair</td>
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<td>T-38, NBL, SF six weeks</td>
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<td>Anterior Cruciate Ligament</td>
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<td>T-38, NBL six months, SF one year</td>
<td>No</td>
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<tr>
<td></td>
<td>tear- complete</td>
<td></td>
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<tr>
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<td>Anterior Cruciate Ligament</td>
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<td>No</td>
<td>T-38, NBL, SF six weeks</td>
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<tr>
<td></td>
<td>tear- partial</td>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td>Osteoarthritis w/o replacement</td>
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<td>Yes</td>
<td>T-38, NBL six months</td>
<td>No</td>
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<tr>
<td></td>
<td>Osteoarthritis w/ replacement</td>
<td>2</td>
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<td>T-38, NBL six months, SDSF one year</td>
<td>Yes</td>
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<tr>
<td>Cervical Spine</td>
<td>HNP w/ radiculopathy ACDF</td>
<td>4</td>
<td>Yes</td>
<td>T-38, NBL six months, SF one year</td>
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<td>HNP w/o radiculopathy</td>
<td>2</td>
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<td>T-38, NBL six weeks SF three months</td>
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<tr>
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<td>Degenerative disc disease</td>
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<td>T-38, NBL six weeks SF three months</td>
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<td>Lumbar Spine</td>
<td>HNP w/ radiculopathy</td>
<td>1</td>
<td>Yes</td>
<td>T-38, NBL, SF six weeks</td>
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<td>HNP w/o radiculopathy</td>
<td>11</td>
<td>No</td>
<td>T-38, NBL six weeks SF three months</td>
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<td>Degenerative disc disease</td>
<td>3</td>
<td>No</td>
<td>T-38, NBL six weeks SF three months</td>
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</tbody>
</table>

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

UCSD Ortho Grand Rounds
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)

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Research Article

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

Richard A. Schilling, Charles H. Mathews, Jonney A. Jones, and Mary L. Wear

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)
ISS Medical Capabilities Comparison

Current Capabilities

Hospital
Polar Ops
Submarine
Ambulance
Everest Base Camp

Diagnostics  Therapeutics  Communication  Evacuation  Personnel

UCSD Ortho Grand Rounds
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

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

Number of Injuries

Results - 9-Sep-18
UCSD Ortho Grand Rounds
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
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
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%

Pain Intensity

9-Sep-18  UCSD Ortho Grand Rounds
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
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
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
- Muscle skeletal injuries
- Nerve trauma
- Miscellaneous

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

LFCN

ASIS

IL

Lateral femoral cutaneous nerve

Inguinal ligament

Affected area

The nerve is compressed by the inguinal ligament.

Source: BMJ Manchester Univ © 1998-2013 BioMed Central Ltd


Future Considerations
Thank You
Injuries to Crewmembers during Nominal Operation of Soyuz Landing Systems Bibliography

Травмы членов экипажа во время спуска на КК Союз


Seoul, South Korea. Первый Ю. Корейский астронавт госпитализирован в больницу с болями в спине. Сеул, Южная Корея.


