NASA Spine Workshop
25-26 Jan 2018

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Acknowledgments

– EMR: T. Bradley, M. Hughes
– LSAH: M. Laughlin, J. Murray, M. Van Baalen
– ASCRs: B. Nieschwitz, M. Guilliams, S. Latham
– Astronaut office: K. Rubins, J. Williams, T. Marshburn, K. Lindgren, D. Morgan, R. Bresnik
– Bone lab: J. Sibonga
– Muscle lab/Exercise lab: M. Downs, J. DeWitt, L. Goetchius, B. Cromwell
– FMC: L. Smith, R. Shah
– SD Mgmt: R. Reed, S. Moynihan
– NASA Flight Surgeons
Day 1 Agenda

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

9 September 2018
NASA Spine Workshop 2018
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>0800-0900</td>
<td>Background and summary of recommendations from Day 1 and short Intro from Alan Hargens</td>
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<tr>
<td>0900-0940</td>
<td>Update on IVD cervical work</td>
</tr>
<tr>
<td>0940-1020</td>
<td>Overview of in-flight IVD ultrasound study</td>
</tr>
<tr>
<td>1020-1100</td>
<td>Overview of in-flight spinal lengthening study</td>
</tr>
<tr>
<td>1100-1130</td>
<td>Assessing/Screening muscle function - Russian experience</td>
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<tr>
<td>1130-1200</td>
<td>Role of the vertebral endplate in LBP and spine disorder</td>
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<td>1200-1300</td>
<td>Break for lunch</td>
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<tr>
<td>1300-1500</td>
<td>Future directions and countermeasures for spine</td>
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<tr>
<td></td>
<td>- Come up with list of countermeasures and screening measurements</td>
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<td></td>
<td>- Discussion about value of a possible in-flight muscle ultrasound study</td>
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<tr>
<td></td>
<td>- Develop a workshop summary for supporting a study for future validation studies</td>
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<tr>
<td></td>
<td>- Pre-flight paraspinal muscle training guidelines</td>
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</tbody>
</table>
Participants

**Subject Matter Experts**
- J. Bob Blacklock, MD - Neurosurgery Houston Methodist
- Paul Holman, MD - Neurosurgery, Houston Methodist
- John Cianca, MD - PM&R Memorial Hermann Houston
- Benoy Benny, MD - PM&R The Spine and Sports Medicine Center Houston
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**NASA Astronauts**
- Jeff Williams, COL (ret.) USA
- Kate Rubins, PhD
- Kjell Lindgren, MD, MPH
- Randy Presnik, COL (ret.) USMC
- Drew Morgan, MD, LTC USA
- Jonathan Kim, MD, MAJ USN
- Frank Rubio, MD, MAJ USA

**Russian Cosmonaut and Flight Surgeon**
- Oleg Kotov, MD
- Ilya Rukavishnikov, MD
Background

**NASA MSK Summit 2005**

Microgravity associated lumbar spine pain in astronauts

**NASA IVD Damage Summit 2009**

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

**NASA Low Back Pain Meeting 2015**

Evaluation of lumbar spine pain

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

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

SOURCE: Marshburn, 2000b.
Objectives

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

• To perform an evaluation of reported post-flight back pain cases and relevant spaceflight risk factors in US ISS astronauts

• Data since the 2015 summit was added and additional risk factors investigated
Spaceflight Related Risk Factors

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

• A case was defined as a reported event of back pain or injury to the cervical, thoracic, lumbar, sacral or coccyx spine regions.

• Pre-flight case within L-6 months, L-3 years, and any pre-flight report

• Post-flight case before R+45 and R+1 year

• Data sources
  – EMR
  – Astronaut Strength, Conditioning and Rehabilitation
  – Private Medical Conferences tool
  – Space Medicine Operations Team
ISS Expeditions 1-51

• US Crewmembers
  – 40 Male astronauts (4 have stayed on ISS twice, 1 has stayed on ISS three times)
  – 10 Female astronauts (1 has stayed on ISS twice, 1 has stayed on ISS three times)
  – Average age: 47.5 years
  – Average length of mission: 169 days
    • 341 days (longest) to 58 days (shortest)

• Individuals not included in this presentation
  – Russian Cosmonauts
  – International Partner Astronauts (ESA, CSA, and JAXA)
NASA Astronauts by Sex and Military Experience

Active NASA Astronauts by Sex, n=45

69% Males
n=31
Avg. Age = 51.4±5.7

31% Females
n=14
Avg. Age = 46.0±5.9

Males by Military Experience
n=26
Military experience 84%

n=5
No military experience 16%

Females by Military Experience
n=3
No military experience 79%

n=11
Military experience 21%
Number of Cases

- Anytime prior to launch – 34 (58%)
- L-3 years to launch – 16 (27%)
- L-6 months to launch – 6 (10%)
- Landing to R+45 days – 15 (25%)
- Landing to R+1 year – 21 (36%)
# Reports of Spine Pain by Region in ISS astronauts

<table>
<thead>
<tr>
<th>Region</th>
<th>Pre-flight</th>
<th>In-flight</th>
<th>Post-flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>5</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Cervical</td>
<td>14</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Thoracic</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Lumbar</td>
<td>31</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>Sacrum</td>
<td>1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Coccyx</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>57</strong></td>
<td><strong>27</strong></td>
<td><strong>57</strong></td>
</tr>
</tbody>
</table>

*Denominator is 50 US ISS astronauts*
Multivariate Analyses

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

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

• Regardless of cause – post-flight back pain & injuries are reported more often since ARED was deployed and FTT type studies began

• No single spaceflight risk factor explains the data – 80% of variance is unaccounted for

• Likely multi-faceted factors resulting in post-flight back pain and injury cases
Current annual screening for spinal disorders for US astronauts

- Annual flight physical
- Further investigation into spine health depends on presenting symptoms to the flight surgeon
- DXA BMD is performed as follows:
  - L-21/18 months (w/AME) 60 min
  - L-180/30 d (as close to launch as possible) 60 min
  - R+ 5/30d 60 min
  - then as clinically indicated to assess BMD recovery
- Plain radiographs or MRI/US are not routinely performed on astronaut selectees or US astronauts unless clinically indicated
Case Reports (12)

- A select number of astronaut lumbar spine pain/injury cases are presented, and are generally representative of all cases seen at NASA over 50 yrs
- Pre-NASA occupational hx, BMDs, Radiation exposure, and relevant imaging will be discussed
- All laboratory values and body mass composition are considered WNLs unless otherwise noted
- Non-MSK related medications (e.g. anti-HTN, statins, thyroid) are not listed
- All in-flight reports were conducted during the Private Medical Conference (PMCs)
- 25-OH Vit D, ESR, TFTs, LFTs, CBC w/diff, CRP, testosterone, Intact PTH, Ionized Ca, Osteocalcin, Alk Phos, N-Telopep, C-Telopep otherwise unremarkable
- Lumbar spine imaging studies are not performed at astronaut selection or pre-mission assignment unless clinically indicated
- Pain ≠ injury
- A number of astronauts have had cervical spine issues during their career
- Aside from clarifications on data or time course, let’s hold questions until the end of the case presentations
SABP is present in the early phase of spaceflight, with a peak prevalence on flight day 2 and none reported after flight day 12.

Flight Days Associated With SABP

<table>
<thead>
<tr>
<th>Flight Day</th>
<th>Crew</th>
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<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>
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<tr>
<td>FD6</td>
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<td>FD7</td>
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<td>FD8</td>
<td>16</td>
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<td>FD9</td>
<td>13</td>
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<tr>
<td>FD10</td>
<td>8</td>
</tr>
<tr>
<td>FD11</td>
<td>2</td>
</tr>
<tr>
<td>FD12</td>
<td>1</td>
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Results

• The incidence of SABP has been determined to be 53-68% among astronauts in the U.S. space program

• Most cases of SABP are mild, self-limited, or respond to available treatments

• There are no currently accepted preventive measures for SABP

• It is difficult to predict who will develop SABP

• The precise mechanism and spinal structures responsible for SABP are uncertain

• There was no documented evidence of direct operational mission impact related to SABP

• There is potential mission impact related to uncontrolled pain, sleep disturbance, or the adverse side effects of anti-inflammatory medications
Etiology of In-flight back pain

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

Nada Chair by Nada-Concepts, Inc.
In-Flight Musculoskeletal Injuries

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

Data courtesy of L. Goetchius
DXA Bone Mineral Density

Data courtesy of J. Sibonga, PhD

- Means

1. Pre-ARED
   n=24

2. ARED
   n=19

3. Alendronate + ARED n=7

p<0.05, Pre vs. Post
p<0.05, Alendronate + ARED vs. Pre-ARED
p<0.05, Alendronate + ARED vs. ARED

Denotes Change within Measurement Error
ISS Astronauts: Pre and Post Flight VO2 Peak

Data courtesy of M. Downs, PhD
Radiation

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

2. Crewmembers are radiation workers
   Limits for mission and career exposure are set by the National Council on Radiation Protection

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

4. Exposure monitored by active and passive dosimeters

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

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

Risk of Herniated Nucleus Pulposus Among U.S. Astronauts

Herniated Nucleus Pulposus (HNP) is usually a degenerative disc disease, although some term it a disc prolapse. Herniation of the nucleus pulposus is usually due to degeneration of the annulus fibrosis. This may result from a tear in the annulus or a disruption of the annular architecture to the vertebral body. Herniations in the cervical and lumbar spine that result in symptomatic radicular pain are typically due to extrusion of 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 regions makes the occurrence of direct central extension of disc material into the spinal canal less likely. When this occurs, direct compression of the spinal cord or cauda equina can occur.

The intervertebral disc is formed by the central nucleus pulposus, the outer annulus fibrosis, and the cartilaginous vertebral end plates. Each of these structures consists primarily of collagen, proteoglycans, and water.
Results

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

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

Alan H. Feiveson,1 Claudia M. Méndez,2 Jeffrey T. Somers3

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

Background:

• In a retrospective study following 330 U.S. astronauts over a span of approximately 50 years, 51 of the astronauts were found to have experienced pronounced disk herniation (HNP = herniated nucleus pulposus) either during their careers as active astronauts or after retirement.

• (Earlier study) The number of cases of HNP appears to be highest in the first year after mission landings, and then drops off precipitously afterwards.

Figure 1. HNP Cases
(earlier study*)

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

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

Pro: Higher incidence of HNPs relatively soon after space missions.
Con: Substantial number of HNPs before astronauts’ first missions or well after their last missions.
Assessing the Effect of Spaceflight on the Propensity for Developing Disc Herniation

Does spaceflight increase the risk of developing a HNP?

Data

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

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

Axial unloading in $\mu g \rightarrow$ spinal curve flattening $\rightarrow$ increased IVD height $\rightarrow$
spine pain $\rightarrow$ $\rightarrow$ $\rightarrow$ spinal muscle atrophy

“Pain is a signal that the body has changed”

*Mission assigned cosmonauts have pre- and lost-flight screening lumbar spine MRIs every 2 hrs
• Post-flight reconditioning program
  – Cosmonauts undergo a gradually accelerated re-adaptation to 1g over a period of 6 months
  – R+0-R+30
    • Massage
    • Swimming
    • Proprioception
    • Light cardio
  – R+30-R+180
    • Gradually re-introduce loading exercises
    • Aerobic conditioning (running)
    • Continue Massage
UCSD IVD Project
Methods

**Supine MRI (3T)**
- Lumbar lordosis (L1-S1)
- Water content
- Disc health
- Muscle functional cross-sectional area
- Vertebral endplate and disc pathology

**Pre-flight, R+1, R+45**

**Upright MRI (0.6T)**
- Lumbar lordosis (L1-S1) in upright posture (load bearing)

**Functional testing**
- Timed Biering-Sorensen test (seconds) for lumbar paraspinal muscle endurance

**Dynamic radiographs**
- Intervertebral ROM in active (standing) and passive (lying) postures

**Pre-flight, R+1**
Negligible changes in disc swelling

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

*(Chang et al. 2016)*

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

*(Bailey et al. 2018)*

![IVD T2 Mapping](image-url)
Crew with Chronic Back Pain More Likely to Have Endplate Lesions

Endplate Lesions include ‘irregularities’ and Modic Changes
MRI Findings May Associate with Future Pain

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

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

Change in MC1, endplate damage, and disc height associate with change in ODI
Luoma, 2016
Lumbar paraspinal muscle changes

Post-flight significant changes found for:

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

On average, recovered to +4.1\% pre-flight

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

On average, recovered to +1.8\% pre-flight
Crew with severe post-flight spine conditions had highest levels of pre-flight multifidus fat content.
Post-spaceflight increase in multifidus = increase in lordosis
Post-spaceflight decrease in multifidus = decrease in lordosis

Change in upright lumbar lordosis (%)

<table>
<thead>
<tr>
<th>Change in multifidus (%)</th>
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<tbody>
<tr>
<td>-35</td>
</tr>
<tr>
<td>-25</td>
</tr>
<tr>
<td>-15</td>
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<tr>
<td>-5</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>25</td>
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</tbody>
</table>

Subject A
- Pre-flight: 46°
- Post-flight: 56°
- ΔLL = +22.0%
- Δmultif = +14.1%

Subject B
- Pre-flight: 43°
- Post-flight: 38°
- ΔLL = -12.9%
- Δmultif = -29.1%
Prolonged spinal unloading

\[ \downarrow \text{Multifidus} \quad \downarrow \text{lean muscle} \]

\[ \downarrow \text{Lumbar lordosis} \quad \downarrow \text{Intersegmental ROM} \]

Stiffness + abnormal postural loading on disc + Pre-existing vertebral endplate pathology → Risk for disc injury and low back pain
Summary

**Known**

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

**Unknown**

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

1. Do the inflight changes in the lumbar spine contribute to immediate spine pain and delayed post-flight spine disease?

2. Should we add pre- and post-flight non-contrasted lumbar spine MRI to astronaut selection and mission assigned occupational medicine surveillance rqts?
   a. Should we consider implementing on orbit use of ultrasound for diagnostic imaging?

3. Does loss of hip flexion, erector spinae, multifidus, longissimus, spinalis, etc. strength and other spine stabilizing muscles contribute to the etiology of post-flight back pain?
   a. If so, is the current in- and post-flight training program the best we can do to reduce this risk?

4. In astronauts with known pre-existing spinal disease, are the current preventive, clinical and rehabilitation interventions the best we can do?

5. With regards to future microgravity exercise devices, what capability should be added to mitigate the spinal changes discussed?
Panel Recommendations

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

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

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

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

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

• Used to diagnose musculoskeletal injuries and guide treatment plans and predict return to duty timeframe

• MSK conditions occurring on-orbit
  – Recurrent knee pain
  – Hamstring strains*
  – Finger dislocations
  – Foot trauma related to CEVIS
  – EMU doffing shoulder injury
  – Low back pain/injury
  – Cervical spine pain

*Used to diagnose on-orbit in ISS crewmember