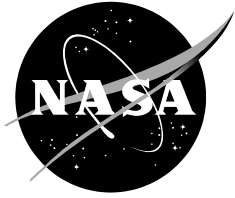


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NASA 2018 Spine Workshop

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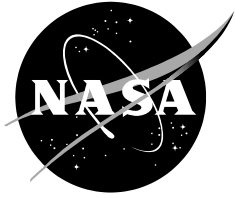
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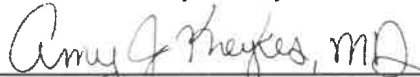
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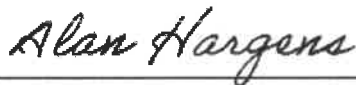


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ACRONYMS

AAR	After-Action Report
ARED	Advanced Resistive Exercise Device
ASCR	Astronaut Strength, Conditioning, and Rehabilitation
CEVIS	Cycle Ergometer Vibration Isolation System
CNES	Centre National d'Etudes Spatiales (French Space Agency)
CSA	Cross-Sectional Area
DXA	Dual Energy X-ray Absorptiometry
ESA	European Space Agency
FCSA	Functional Cross-Sectional Area
HNP	Herniated Nucleus Pulposus
IBMP	Institute of Biomedical Problems
IVD	Intervertebral Disc
MRI	Magnetic Resonance Imaging
NSAID	Non-Steroidal Anti-Inflammatory Drug
SABP	Space Adaptation Back Pain
SME	Subject Matter Expert
UCSD	University of California, San Diego
UCSF	University of California, San Francisco
US	Ultrasound

1.0 INTRODUCTION

The NASA Spine Workshop of January 25-26, 2018, was the fourth meeting of its kind.

In 2005, the Operational and Research Musculoskeletal Summit determined that microgravity is associated with lumbar spine pain in U.S. astronauts.¹ It was recommended that pre- and post-flight magnetic resonance imaging (MRI) would be beneficial to better evaluate herniated discs in the lumbar and cervical regions; however, MRI was not advised for astronaut selection purposes. The addition of in-flight core stabilization exercises was also recommended. Further, it was advised that ultrasound (US) be utilized to examine disc volume to validate protocols against the gold standard (MRI).¹ Neither evaluation with MRI nor US were adopted. In-flight core stabilizing exercises were not implemented due to the encumbrance of the exercise and equipment in a microgravity environment.

In 2009, the NASA Intervertebral Disc (IVD) Damage Summit concluded that IVD damage following spaceflight is evident in U.S. astronauts.² However, it recognized the lack of clarity in the relationship between microgravity and spinal changes resulting in pain. It was recommended that the study of IVD damage be extended to include the entire spinal column and that prospective (*i.e.* pre-flight) imaging of astronauts should be deemed a high priority.² However, no pre-flight imaging of the spine was adopted. (Note that imaging occurred on a case-by-case basis if clinically indicated for diagnosis and treatment of injury, at the discretion of the flight surgeon.)

In 2015, the NASA Low Back Pain Meeting was held to further evaluate lumbar spine pain in the U.S. astronaut population. Objectives included discussing the anatomic and physiologic changes that occur in the human spine in microgravity, whether these play a role in developing in-flight back pain and chronic back pain after return to Earth, predisposing anatomic and physiologic factors, current preventive measures for in-flight lumbar back pain, the best approach to identify lumbar spine disease, and measures of mitigating pain in the presence of disease.³ Although the cumulative data presented from observed astronaut pre-, in-, and post-flight spine disorders compelled the subject matter experts (SMEs) to consider requiring pre- and post-flight MRI imaging as a screening tool for existing spine disease, the expert panel was hesitant to advise this in an asymptomatic and highly physically functioning patient population. Consequently, no imaging was formally recommended, unless clinically indicated.

2.0 PROJECT APPROACH

The NASA Spine Workshop (January 25-26, 2018) provided an evidenced-based, expert review of relevant literature and current knowledge of back pain in space. It reviewed previous findings from the Operational and Research Musculoskeletal Summit of 2005, the NASA Intervertebral Disc Damage Summit of 2009, and the NASA Low Back Pain Meeting of 2015. The primary focus of this workshop was pre-, in-, and post-flight conditioning programs; back pain in space; and post-flight spine disorders. Specifically, the workshop proposed etiologies of space-related back pain/spine disorders. It further focused on methods of evaluating and monitoring spine disorders and how to utilize these methods to advance countermeasures.

Background

There is an increased prevalence of spine disorders pre-, in-, and post-flight in U.S. astronauts.

Current astronaut selection criteria for spine disorders require that an applicant be asymptomatic of any spine disorder and fully functional in his or her performance of duties. Orthopedic evaluation is required for a history of traumatic, degenerative, or congenital disorder of the spine that could interfere with performance of duties, such as: herniated nucleus pulposus (HNP), spondylolisthesis, spina bifida, fractures and dislocations, scoliosis, kyphosis, or lordosis. Ankylosing spondylitis is disqualifying.⁴

Once accepted into the astronaut corps, screening for spinal disorders consists of the annual flight physical and dual energy x-ray absorptiometry (DXA) scanning of bone mineral density. Upon assignment to a long-duration mission, DXA scanning occurs at 21 and 18 months prior to launch, 180 and 30 days prior to launch, and both five and 30 days after return. Further investigation of spine health is at the discretion of the flight surgeon, based on clinical suspicion of pathology.

During terrestrial training, the astronauts have exposures that could relate to spine disorders, such as +G_z (head-to-toe) exposure in T-38 aircraft; in-suit training at the Neutral Buoyancy Laboratory; and the pre-flight exercise program all assigned astronauts undergo for aerobic conditioning, resistive loading, and to familiarize them with on-orbit exercise equipment. On Russian Soyuz launch and landing, the spine is also loaded in the +G_x (chest to back) orientation, which could pose an additional risk for spinal disorders. Space Shuttle commanders, pilots, and mission specialists were oriented to +G_z exposure.

The etiology of in-spaceflight back pain has been postulated to be secondary to IVD changes, thoracolumbar myofascial changes, facet arthrosis, stretching/atrophy of the spinal stabilizers and ligaments, and/or pre-existing lumbar degenerative disc disease. However, the causative mechanism(s) remains unknown.

In microgravity, the spine undergoes unique adaptation. Elongation of up to 6% of seated height and 3% of stature occurs.⁵⁻¹⁰ Intervertebral discs are unloaded. Historically, it has been thought that the discs expand as a result; however, recent IVD research disproved this popular belief.¹¹ Core stabilization is also reduced secondary to loss of axial skeleton postural control and stiffness of the hip flexors and hamstrings.¹²

Space Adaptation Back Pain (SABP) is a well-known entity occurring within the first five days of spaceflight, not precipitated by injury, and not attributable to prolonged sitting on the launch pad. Symptoms are generally mild to moderate, localized to the lumbar region, described as an “ache” or “stiffness,” typically occur while sleeping, have no neurologic involvement, and resolve with non-steroidal anti-inflammatory drug(s) (NSAIDs) and/or short-duration muscle relaxants, spinal loading, or bringing the knees to the chest.¹³ The incidence of SABP is 53%-68%. SABP resolves by flight day 12. There are no currently accepted preventive measures for SABP and no method for predicting those who will be afflicted. The mechanism and structures involved in the generation of pain are unknown. There is no evidence of operational impact of SABP; however, there is *potential* mission impact related to uncontrolled pain, sleep disturbance, or adverse side effects of NSAIDs.¹³ Ultrasound is available on orbit and has been used to diagnose musculoskeletal injuries and guide treatment but has not been utilized for evaluation of back pain.

In microgravity, U.S. astronauts exercise at least 12 hours a week to mitigate the musculoskeletal issues of bone resorption and muscle atrophy and stay as physically fit as possible. Current in-flight musculoskeletal countermeasures include the T2 treadmill, the Cycle Ergometer Vibration Isolation System (CEVIS), and the Advanced Resistive Exercise Device (ARED).

Post-flight U.S. astronauts have a 4.3-fold increased incidence of HNP as compared to non-astronaut controls.¹⁴ This risk is greatest immediately post-flight (35.9x increased risk in the first year) and has a predominance for the cervical region of the spine. The risk does not appear to be correlated to prior increased +G_z experience.¹⁴

Post-flight, U.S. astronauts undergo vigorous reconditioning. Immediately after landing, this includes dynamic and static stretching, mobility, balance, and proprioceptive training. Aerobic exercise is introduced and gradually the intensity is increased. Strengthening is added. This program is implemented by the Astronaut Strength, Conditioning, and Rehabilitation (ASCR) team. Functional fitness assessments to monitor progress occur at five, seven, and 30 days after return. These are compared to pre-flight baseline performance in each of six different areas measuring strength, stamina, flexibility, and agility.

2.1 Workshop

During this 2-day, face-to-face workshop, a panel of SMEs were invited to present findings and discuss the following objectives:

- 1) What medical surveillance studies might be beneficial given the prevalence of the problem (pre-, in-, and post-spaceflight back pain) 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 disorders 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 degenerative disc disease?
- 5) What long-term complications may develop years after spaceflight exposure?
- 6) Given the known spinal changes, provide considerations for future spaceflight exercise devices.

The SMEs comprised a panel that reviewed the above objectives and provided seven recommendations (Appendix 1). Minutes of the workshop were recorded and used in the compilation of this after-action report.

2.2 Deliverables

Upon completion of the workshop, the SME panel designated seven recommendations, presented in Appendix 1. This report will be utilized in support of a requirement for pre- and post-flight MRI imaging of the spine. Presentation of this material to the Human System Risk Board in support of a new directive for back pain/spine disorders is anticipated following this report. Publication of this material in a peer-reviewed scientific journal is also anticipated. Following further evaluation of the etiology of back pain/spine disorders, additional work is anticipated and will be performed as indicated.

3.0 MILESTONES/DELIVERY

1. Developed roster of workshop attendees.
2. Secured necessary authorization and funding.
3. Secured appropriate facilities.
4. Invited attendees and guest lecturers.
5. Developed agenda and objectives of workshop with guest lectures from SMEs.
6. Hosted Spine Workshop, January 25-26, 2018, at NASA Johnson Space Center, Houston, Texas.
7. SME panel developed seven consensus recommendations (Appendix 1).
8. Wrote after-action report (AAR).
9. Submitted AAR to Space Medicine, Human Health and Performance Directorate, Johnson Space Center.

4.0 MANAGEMENT PLAN

NASA flight surgeon Dr. Richard A. Scheuring, Team Lead for Musculoskeletal-Sports Medicine and Rehabilitation at the Johnson Space Center, has managed this project as part of an ongoing effort to investigate the etiology, improve surveillance, and improve countermeasures for back pain and spine disorders in- and post-flight. He was responsible for coordination of the workshop and appropriate follow-up, with assistance from flight surgeon Derek Nusbaum acting as deputy for the workshop. Acknowledgments for their assistance in developing and participating the workshop include:

- KBR Flight Surgeon: Derek Nusbaum, MD, PhD
- NASA Flight Medicine Clinic Medical Records Technicians: T. Bradley, M. Hughes
- NASA Lifetime Surveillance of Astronaut Health: M. Laughlin, J. Murray, M. Van Baalen
- NASA ASCR Team: B. Nieschwitz, M. Guilliams
- NASA Astronaut Office: K. Rubins; J. Williams; T. Marshburn; K. Lindgren, MD; D. Morgan, MD; R. Bresnik; Jonny Kim, MD; Frank Rubio, MD; and Mike Barratt, MD.
- NASA Bone Lab: J. Sibonga
- NASA Muscle Lab/Exercise Lab: M. Downs, J. DeWitt, L. Goetchius, B. Cromwell
- NASA Flight Medicine Clinic: L. Smith, R. Shah
- NASA Space Medical Operations Management: R. Reed
- NASA Flight Surgeons
- NASA Research team (SK): Judy Hayes
- KBR Flight Surgeons/Radiologist: Eric Kerstman, MD; Ashot Sargsyan, MD
- University of California, San Diego (UCSD) and University of California, San Francisco (UCSF) Intervertebral Disc Project Team
- SMEs in the fields of Neurosurgery, Orthopedics, Physical Medicine & Rehabilitation, Pain Management, Physical Therapy, Neuroradiology, and Vertebral End Plate Intervertebral Disc Pathophysiology
- Russian colleagues: Dr. Oleg Kotov, Chairman of the Institute of Biomedical Problems (IBMP) in Moscow, and Ilya Rukavnishkov

5.0 PROJECT RESULTS

The Spine Workshop was hosted January 25-26, 2018, at the NASA Johnson Space Center in Houston, Texas.

The first day of the workshop was a closed-door session for NASA flight surgeons, astronaut physicians, UCSD/UCSF research teams, and the SME panelists. The workshop started by discussing the above relevant background information, as well as goals and objectives. Case reports of lumbar spine pain and injury pre-, in- and post-flight in U.S. astronauts were presented by Dr. Scheuring and Dr. Nusbaum. Of the cases presented, corresponding active astronauts attended to present their perspective of their condition to the panelists. The epidemiology of back pain in the active astronaut corps was discussed. Pre-, in-, and post-flight conditioning protocols were presented by the ASCR team and reviewed by the SMEs compared to current practice standards in the field. A status report of the intervertebral disc research conducted by the UCSF and UCSD was presented. Countermeasures, injury prevention, and treatment strategies were evaluated. Best practices for back rehabilitation in the terrestrial environment were reviewed. Future in-flight exercise devices were presented. The day closed with a discussion that generated recommendations from the SMEs present. A more detailed explanation of the agenda and presentations from the first day is included in Appendix 2.

The second day of the workshop was an open-door session. A comprehensive review of the recommendations from the first day, an update on intervertebral cervical disc work, and an overview of in-flight intervertebral disc ultrasound and spinal lengthening studies was conducted. Russian colleagues presented their experience with assessing and screening spinal muscle function. Finally, future directions regarding countermeasures for the spine were discussed. A more detailed explanation of the presentations and agenda from the second day is included in Appendix 3.

The attendees of the Spine Workshop were as follows:

Subject Matter Expert Attendees

- Ron Alkalay, PhD
Dr. Alkalay received his PhD in Engineering and Materials Science from Queen Mary and Westfield College, London University in London, England. He is currently an Assistant Professor of Orthopedic Surgery at Beth Israel Deaconess Medical Center in Boston, Massachusetts. His research focuses on vertebral structures and their failure. He has focused on developing novel magnetic resonance imaging techniques to study disc degeneration.

- Jeannie Bailey, PhD

Dr. Bailey received her PhD in Biological Anthropology/Anatomy with training in human biology, biostatistics, and population health outcomes from the University of Washington in Seattle, Washington. She is currently an Assistant Adjunct Professor of Orthopaedic Surgery at the UCSF School of Medicine. She has over a decade of interdisciplinary research experience in orthopaedic health outcomes focused on lumbar spinal conditions and low back pain. Her clinical research focuses on how disruptions in passive and active stability of the lumbar paraspinal muscles and postural biomechanics can lead to injury and low back pain in the U.S. astronaut population. In 2017 she was awarded the “Outstanding Paper Award” by *The Spine Journal* for her intervertebral disc research with U.S. astronauts as part of the Intervertebral Disc group at the UCSF. In 2018 she also received First Place Presentation recognition, Postdoctoral Fellow category, from the NASA Human Research Program.

- Benoy Benny, MD

Dr. Benny received his MD from the University of West Indies-Faculty of Medical Sciences in Trinidad. He completed a residency in Physical Medicine & Rehabilitation Alliance at Baylor College of Medicine/University of Texas in Houston where he was the chief resident. He then completed an Interventional Spine/Pain and Musculoskeletal Fellowship at the University of Michigan in Ann Arbor, Michigan. He is board certified in both Physical Medicine & Rehabilitation and Pain Medicine. Since 2006 he has been an Assistant Professor in the Department of Physical Medicine and Rehabilitation at Baylor College of Medicine in Houston and since 2007 has served as the Director of the Fellowship in Interventional Spine, Sports, and Pain Medicine at Baylor. He is actively involved in the research community of the International Spine Intervention Society. He is also a member of the American College of Sports Medicine, the Academy of Physical Medicine and Rehabilitation, and the North American Spine Society.

- Jerry Bob Blacklock, MD

Dr. Blacklock received his MD from the University of Mississippi School of Medicine in Jackson, Mississippi. He completed residency in Neurosurgery at the University of Minnesota in Minneapolis, Minnesota. He is currently an Emeritus Professor of Neurosurgery at the Institute for Academic Medicine Houston Methodist. He has extensively researched the human spine, most recently in relation to the role of the psoas muscle in disease. He has served as a consultant in neurosurgery for NASA for the past 20 years, performing spine surgery on over 20 U.S. astronauts for a variety of spine disorders. He also served as a SME for the 2009 and 2015 NASA spine summits.

- Douglas Chang, MS, PhD, MD
Dr. Chang received his MS in Mechanical Engineering from The University of Washington in Seattle and a PhD in Bioengineering, and MD, from the UCSD. He completed a residency in Physical Medicine & Rehabilitation at Stanford University in Palo Alto, California. He then completed a Fellowship in Interventional Spine & Sports Medicine at Schulthess Klinik in Zurich, Switzerland. He is currently the Chief of the Division of Physical Medicine & Rehabilitation, and a Clinical Professor of Surgery, at the UCSD. He has served as a medical consultant for the San Diego Chargers NFL team (2013-2017) and San Diego Padres MLB team (2017- present). He is also currently a medical consultant at the U.S. Olympic Training Center in Chula Vista, California, and serves as the lead physician for the San Diego Crew Classic Rowing Regatta. San Diego Magazine has honored him as one of the “Top Doctors, San Diego” for the last 8 years.
- John Cianca, MD
Dr. Cianca received his MD from Albany Medical College in New York. He completed a residency in Physical Medicine & Rehabilitation at Strong Memorial Hospital in Rochester, New York, where he also served as Chief Resident. He then completed a Sports and Performing Arts Fellowship at Baylor College of Medicine at The Institute for Rehabilitation and Research in Houston, Texas. He is currently an Adjunct Associate Professor of Physical Medicine & Rehabilitation at Baylor College of Medicine. He is a Fellow of the American College of Sports Medicine, member of the American Medical Society for Sports Medicine, and member of the American Institute of Ultrasound Medicine. In 1998 he received the Teacher of the Year award from the Department of Physical Medicine and Rehabilitation at Baylor College of Medicine. He was distinguished as one of the “Best Doctors in America” eight years in a row and a “Houston Top Doctor” by *Inside Houston* magazine twice. The American Academy of Physical Medicine & Rehabilitation honored him with the 2013 Distinguished Clinician Award. Additionally, he is board certified in acupuncture and diagnostic medical sonography. Since 2012 he has served as a consultant/trainer/owner of Musculoskeletal Ultrasound Consultants, LLC.
- Dezba Coughlin, PhD
Dr. Coughlin received a PhD in Bioengineering from the University of California, Berkeley and Joint San Francisco Group. She is multilingual and has over 21 years of experience in biomedical engineering and 10 years of management experience. She is currently the Director of Operations of the University of California at San Francisco Laboratory for Orthopaedic Bioengineering directed by Jeffrey C. Lotz, PhD, which has researched the role of the multifidus and erector spinae musculature pre- and post-flight in the astronaut population.

- Chris Gilligan, MD, MBA

Dr. Gilligan obtained his MD from Yale University School of Medicine in New Haven, Connecticut, and his MBA from Harvard Business School in Boston, Massachusetts. He completed a residency in Emergency Medicine at Brigham and Women's Hospital, followed by a Fellowship in Pain Management at Massachusetts General Hospital, both located in Boston, Massachusetts. He is currently the Chief of the Division of Pain Medicine at Brigham and Women's Hospital. His clinical expertise focuses on pain disorders of the spine. In 2019 he was distinguished by *Boston Magazine* as a "Top Doctor." Similarly, in 2017 he was distinguished as one of "America's Top Doctors" by *Castle Connolly*.

- Ola Grimsby, PT, DMT, FAAOMPT

Dr. Grimsby attended sport college in Denmark, followed by the Norwegian State Physiotherapy School and the Physical Therapy Department of Health in Oslo, Norway. He then completed four years of postgraduate studies in orthopedic manual therapy with the Nordic Special Group for Manual Therapy and the Norwegian Physical Therapy Association. He has served as a physical therapist for various national sports teams and founded private practices in Norway before he became a permanent resident of the United States. He is a certified manual therapy instructor in the Norwegian National Program. He has served as chair of the Nordic Group of Specialists in Manual Therapy as well as chair of the Instructors Council and the Manual Therapy Section of the Norwegian Physical Therapy Association. He was an instructor at the International Seminar School in Europe and at the Institute for Orthopedic Manual Therapy in the United States. He was Norway's first executive member at the International Federation of Orthopaedic Manipulative Physical Therapists and a founding member and treasurer of the American Academy of Orthopedic Manual Physical Therapy. Dr. Grimsby is the founder of the Ola Grimsby Institute International Consortium of Orthopedic Manual Therapy with educational programs and independent study programs worldwide. He has authored numerous books and articles in several languages. He started the first Norwegian Journal of Orthopedic Manual Therapy and was an associate editor at the commencement of the Journal of Orthopedics and Sports in the United States. He has served as adjunct faculty at numerous universities in the United States and Europe. His extensive resumé includes awards and honorary memberships from organizations in Europe, Asia, and the United States.

- Alan R. Hargens, PhD, FAsMA

Dr. Hargens received his PhD in Marine Biology from the Scripps Institution of Oceanography, UCSD. In 1976 he became an Assistant Research Physiologist in the Department of Surgery at the UCSD. Since 1998 he has been a Professor in the Department of Orthopedic Surgery at the UCSD. At the NASA Ames Research Center located at Moffett Field, California, he has served as: Chief of the Space Physiology Branch (1987-1988), a Space Station Project Scientist (1988-1997), Chief of the Gravitational Research Branch (1994-1996), and Senior Research Physiologist of the

Gravitational Research Branch (1996-2000). He has also served as a lecturer in the Department of Aeronautics and Astronautics as well as a Consulting Professor in the Program of Human Biology at Stanford University. He was a member of the NASA/ESA/CNES Review Committee on Development of Countermeasures for Long Duration Space Flight. He was also the chair of the “Integrative and Translational Research for the Human System” panel on a National Academies study that recommended a portfolio and timeline for NASA research in life and physical sciences for the 2010-2020 decade. He also served on the National Academies Decadal Mid-Term Committee to evaluate NASA’s progress and to recommend future research and countermeasures for deep-space missions. He is a fellow of the American College of Sports Medicine. He was bestowed the Outstanding Service Award by the Veteran’s Administration in 1987. He has received at least eight recognitions/awards from NASA for his performance and mentorship. Most notably, he received the NASA Distinguished Public Service Metal in 2017.

- Michael Harrison, MD, PhD

Dr. Harrison received his PhD in Exercise Physiology and Multivariate Statistics at the University of Regina, located in Regina, Canada. He received his MD at Saba University School of Medicine in the Dutch Caribbean. He completed a combined Emergency Medicine, Internal Medicine, and Critical Care residency at Henry Ford Health System in Detroit, Michigan. He is currently completing a fellowship in Aerospace Medicine at the Mayo Clinic in Rochester, Minnesota. He has multiple publications related to spine health and injuries in the aviation community including military helicopter aircrew and astronauts.

- Robert M. Healey, BS, rEDT, MBA

Mr. Healey completed his BS and MBA at the UCSD where he also became a certified electrodiagnostic technician. He has spent over 20 years in orthopedic research. He is currently the lab manager for the Clinical Physiology Laboratory with Dr. Alan Hargens at the UCSD. The lab’s work focuses on creating countermeasures for orthopedic risks associated with long-term spaceflight in U.S. astronauts.

- Paul J. Holman, MD

Dr. Holman received his MD from Wayne State University School of Medicine in Detroit, Michigan. He completed a Neurosurgical residency at Baylor College of Medicine in Houston, Texas, and a Clinical Fellowship at the Cleveland Clinic Foundation in Ohio. Dr. Holman is currently an Assistant Professor of Clinical Neurosurgery at the Institute for Academic Medicine Houston Methodist, Weill Cornell Medical College. He has extensively researched the human spine, with recent research on the role of the psoas muscle in disease.

- Vijay Jotwani, MD
Dr. Jotwani received his MD from the University of Illinois at Chicago Medical School and completed a residency in Family Medicine at the University of Chicago MacNeal Hospital. He completed a fellowship in Primary Care Sports Medicine at Indiana University. He is currently an Assistant Professor of Clinical Medicine at Weill Cornell and Texas A&M Medical Colleges. He is a teaching faculty member for the Primary Care Sports Medicine Fellowship as well as Orthopedic Surgery, Family Medicine, and Internal Medicine Residencies at Houston Methodist. He serves as a team physician for the Houston Astros, the Rice University Athletics, the Houston Ballet, U.S. Soccer, Rodeo Houston, and St. Agnes Academy. He is also a physician member of the Houston Methodist Concussion Center and the Houston Methodist Center for Performing Arts Medicine.
- Danny Keller, PT, DPT, OCS
Dr. Keller received his Doctorate in Physical Therapy from UCSF. He is currently an Assistant Clinical Professor of Physical Therapy at UCSF. He has been trained in a wide variety of techniques and is also certified as an orthopedic clinical specialist. He assists with labs for the UCSF Physical Therapy Doctoral program and Myofascial Decompression Courses.
- Hani Kaykal, MD
Dr. Kaykal received his MD and completed his residency in diagnostic radiology from the American University of Beirut, Faculty of Medicine-Beirut, in Lebanon. He is currently the Director of Neuroradiology at the Methodist Hospital Neurological Institute in Houston, Texas.
- Kenny Leung, PT, DPT, OCS, CSCS
Dr. Leung obtained his Doctorate in Physical Therapy from the University of Southern California, Los Angeles. He is both an Orthopedic Clinical Specialist and Certified Strength and Conditioning Specialist. He is currently an Assistant Clinical Professor of Physical Therapy at UCSF.
- Jeffrey C. Lotz, PhD
Dr. Lotz received his PhD in Medical Engineering from the Massachusetts Institute of Technology/Harvard University in Boston, Massachusetts. He is currently the David S. Bradford, MD, Endowed Chair of Orthopaedic Surgery and Vice Chair for Research at UCSF. He is the founding director of the UCSF Core Center for Musculoskeletal Biology in Medicine and the National Science Foundation Center for Disruptive Musculoskeletal Innovations. He has expertise in spine biomechanics, intervertebral disc biology, and tissue engineering. His laboratory work focuses on identifying mechanisms of disc degeneration, developing novel diagnostics and therapies for low back pain, and the biomechanics of spinal instrumentation. He has earned several awards for his spine research. He is also a deputy editor for the journal *Spine*.

- Roy Riascos-Castaneda, MD
Dr. Riascos-Castaneda received his MD from Escuela Colombiana de Medicina in Bogotá, Columbia. He completed a Diagnostic Radiology residency at the Fundación Universitaria de Ciencias de la Salud, Hospital de San Jose, in Bogotá, Colombia. He completed a Neuroradiology Fellowship at Louisiana State University Health Sciences Center in New Orleans. He is currently a Professor of Diagnostic and Interventional Imaging at the University of Texas Health Science Center at Houston and the McGovern Medical School.
- Joselito V. Sayson, PhD, PT, DMT, MOMT, FAAOMPT
Dr. Sayson received his BS in Physical Therapy from the Royal Pontifical University of Santo Tomas in the Philippines; and his master's degree and doctorate in Orthopedic Manual Therapy at the Ola Grimsby Institute in Baton Rouge, Louisiana. He has been part of several publications regarding back pain afflicting U.S. astronauts. Dr. Sayson is a recipient of the highest alumnus award, "The Outstanding Alumnus Award," conferred by the Royal Pontifical University of Santo Tomas and the Chicago-Filipino-American Hall of Fame 2014 for Science/Humanitarianism. Dr. Sayson, holding dual citizenship with the United States and the Philippines, is an active Lieutenant Commander for the Philippine Coast Guard Auxiliary 107th Squadron. His professional memberships include the American Physical Therapy Association, the Aerospace Medical Association, American Society for Gravitational and Space Research, and the American Astronautical Society. He is also an active member of the Rotary Club International.

Russian Flight Surgeon and Cosmonaut Attendees

- Oleg Kotov, MD
- Ilya Rukavnishkov, MD

NASA/Johnson Space Center Personnel who participated in the workshop are as follows:

Astronaut Office Attendees

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

Astronaut Strength, Conditioning and Rehabilitation (ASCR) Team Attendees

- Mark Guilliams, MS
- Bruce Nieschwitz, MS

Research Attendees

- John DeWitt, PhD
- Megan Downs, PhD
- Mitzi Laughlin, PhD
- Sudhakar Rajulu, PhD
- Judith Hayes, PhD

Flight Surgeon Attendees

- David Alexander, MD
- Joe Dervay, MD
- Steve Hart, MD
- Ben Johansen, DO, MPH
- Eric Kerstman, MD, MPH
- Kathleen McMonigal, MD
- Rob Mulcahy, MD, MPH
- Derek Nusbaum, MD, PhD, MPH
- James Pattarini, MD, MPH
- Steve Piper, DO
- Rick Scheuring, DO, MS
- Ronak Shah, DO, MBA, MPH

6.0 SUMMARY

Many changes to the spine occur in space. Anthropometrically, the spine is unloaded removing compression, the spine elongates, and there is loss of both cervical and lumbar lordosis. A loss of paraspinal, hip, and core musculature occurs. Of note, atrophy and fatty infiltration seen in the multifidus and erector spinae muscle groups are currently under investigation by the Intervertebral Disc research groups at the UCSD and UCSF. These muscle changes likely interact with degenerative features of the discs and vertebrae to increase risk of back pain and spine injury in- and post-flight.

Landing also poses increased risks from prolonged time in the Soyuz capsule and rapid axial loading of the spine on impact. U.S. astronauts are at increased risk for HNP post-flight. No current requirement exists for pre- and post-flight imaging of the spine. It is recommended that pre- and post-flight non-contrast lumbar MRI imaging be adopted for mission assigned crewmembers for occupational surveillance. However, MRI imaging of the spine should not be used for astronaut selection standards.

Functional movement screening should be incorporated into pre- and post-flight conditioning and rehabilitation programs. Pre-flight corrective exercises to improve upper extremity range of motion and deep core stabilizing muscles prior to flight should also be adopted. Current exercise countermeasures on orbit include ARED, CEVIS, and the T2 Treadmill; however, there will not be enough habitable volume for these countermeasures on long-duration missions. Some astronauts have suffered low back pain on orbit during and after T2 (treadmill) sessions, presumably from the loading across the Glenn Harness device that keeps the crewmember attached to the treadmill with varying percentages of body weight. Whether this is a new condition or exacerbation of underlying pathology is not clear. Two decades of crew usage on the CEVIS device has not resulted in any reported lumbar spine pain. Several isolated cases of acute low back pain have resulted from usage of the ARED device. Investigation into mechanisms of injury related to ARED identified individual astronauts having exceeded their exercise prescription from the ASCRs or poor technique in performing dead lift or squat exercises. In one case of suspected on-orbit HNP, no identifiable mechanism of injury was found. Novel exercise devices such as the fly wheel (for Orion) and all-in-one rowing device (for Gateway) are being developed. These countermeasures need to incorporate exercises that target deep core stabilizing muscles, incorporating resistive exercises outside the sagittal plane, including rotational as well as other planes. How these devices influence the microgravity-adapted spine biomechanics is unknown and requires careful evaluation before full-scale implementation.

APPENDIX 1: PANEL RECOMMENDATIONS

Spine Workshop, January 25-26, 2018

1. Based on the supporting data and experience of the panel, the panel believes that in-flight changes in the lumbar spine contribute to immediate spine pain and delayed post-flight spine injury.
2. Based on the supporting data and experience of the panel, the panel believes that loss of hip flexion strength 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 crewmembers for the purposes of occupational surveillance and for the prevention or minimization of spaceflight-related back pain and injury. MRI scans could be used to further characterize associations between pre-flight spine degeneration, flight-induced paraspinal muscle atrophy, and incidence of back pain and injury. The panel currently recommends against MRI imaging for use in U.S. astronaut selection standards.
4. The panel recommends further incorporation of Function Movement Screening into pre- and post-flight conditioning and rehabilitation programs.
5. The panel encourages earlier intervention of low back pain with more invasive modalities on a case-by-case basis depending on what abnormalities can be seen on MRI imaging.
6. The panel recommends the incorporation of pre-flight corrective exercises for improving upper extremity range of motion and conditioning of the deep core stabilizing muscles.
7. The panel recommends incorporating in-flight exercise modalities that target deep core stabilizing muscles. Resistive exercises outside the sagittal plane, especially rotational, as well as other planes should be incorporated into the design of future exercise hardware for deep space and planetary exploration missions. The panel also recommends exploring the rowing exercise capability for deep space missions, however acknowledges that this capability has been minimally tested in a microgravity environment and further evaluation is warranted.

APPENDIX 2: DETAILS OF AGENDA – DAY ONE

Spine Workshop, January 25, 2018

Day 1 Agenda:

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

Details of Sessions:

0800-0830: Welcome and Introduction

Information from this session is included in the body of the AAR.

0830-0900: Background, goals, and objectives

Intervertebral Disc Research Group Update – Presented by Jeannie Bailey, PhD and Jeffrey Lotz, PhD

A group of researchers at the University of California, San Francisco and the University of California, San Diego are currently working on the Intervertebral Disc study. Participants in this workshop from these research groups include: Al Hargens, PhD; Jeffrey Lotz, PhD; Doug Chang MD, PhD; Jeannie Bailey, PhD; Dezba Coughlin, PhD; Jojo Sayson, PhD, PT, DMT; and Robert Healey, MS.

Jeannie Bailey, PhD presented an update on their research. The goal of the study is to investigate how prolonged spinal unloading in space leads to increased risk of disc injury and back pain post-flight.

Study Design

The group is performing a prospective longitudinal study of 12 crewmembers in which they obtain pre- and post-flight imaging using MRI and dynamic fluoroscopy. Pre-flight MRI imaging

will occur within one year of spaceflight (but ideally approximately one month prior to flight). The first six subjects received post-flight imaging one to two days after return from space. The second set of six subjects (data is currently being collected) will have post-flight dynamic fluoroscopy seven days after returning from space and MRI approximately 45 days after returning from space. Each crewmember also participates in a debrief with the research group one year after imaging is obtained to provide feedback and report any back pain or disc injuries that have occurred. At the end of the study, the results will be made known to the participants.

Outcome measures include:

- Subject reported incidence of chronic low back pain or disc injury at one-year follow-up. *Assessed with MRI*
- Multifidus and erector spinae (muscles of the back) at L3-L4 cross-sectional area (CSA), functional cross-sectional area (FCSA) and FCSA/CSA.
- Lumbar lordosis at L1-S1.
- Disc water content, disc height, and disc health.
- Vertebral end plate pathology.

The group has already completed data collection and analysis of six crewmembers and published these findings:¹¹

Results

The group expected the etiology of back pain would be related to disc swelling secondary to unloading. What they found instead was unexpected. Disc water content did not differ pre- and post-flight. However, they saw significant atrophic changes in the musculature of the spine, particularly multifidus and erector spinae. Changes in lordosis were correlated with changes in multifidus FCSA and FCSA/CSA. Active flexion-extension range of motion at the L4-L5 level was also correlated with multifidus FCSA changes. They concluded that multifidus atrophy is strongly associated with loss of lumbar lordosis (flattening of the lumbar spine) and increased stiffness.

Conclusion

This research has enhanced our understanding of the effects of spaceflight on the spine and generated the hypothesis that multifidus atrophy, leading to loss of lumbar lordosis, may lead to post-flight pain and stiffness as well as abnormal postural loading on the discs, predisposing to disc injury. The question remains if multifidus atrophy can *predict* those at risk for low back pain and disc injury. Pre-existing pathology likely also plays a role. The group has found that mean multifidus fat fraction in chronic low back pain patients is positively correlated with patient reported outcomes for low back pain disability. More research is necessary to further investigate the role of pre-existing pathology.

Jeffrey Lotz, PhD also presented data relating degeneration of the vertebral endplate to back pain symptoms. Damage to the vertebral endplate can cause biologic ‘cross-talk’ between the intervertebral discs and the vertebral bone marrow.¹⁵ Bone marrow inflammation can result (seen

as edema on MRI imaging), leading to back pain.¹⁵ The association between endplate damage, vertebral bone marrow edema, and symptoms is well established in terrestrial back pain patients.¹⁵ Paraspinal muscle atrophy can change spinal alignment and stresses on the vertebral endplate, thereby exacerbating symptoms. The interaction between endplate pathology, paraspinal muscle function and back pain has been demonstrated but more research in this area is warranted.¹⁶

0900-1030: Case reports of lumbar spine pain in the U.S. astronauts

Due to the confidential nature of the medical information presented, this session was closed, and details are not presented here.

1040-1110: Review of current pre-, in-, and post-flight injury prevention and treatment strategies among U.S. astronauts – Presented by Mark Guilliams, MS, ASCR

Mark Guilliams, MS, ASCR presented pre-, in-, and post-flight exercise. At the time of assignment to an expedition, the crewmember is concurrently assigned to a flight surgeon and an ASCR. The ASCR assesses function, work capacity, and capability at baseline and tailors a balanced and well-rounded exercise program to fit the individual needs of the astronaut. The focus is on metabolic training, rather than limiting to a single area (*e.g.* only focusing on resistive training). Notably, the program designed for the astronauts is voluntary. A baseline assessment is taken 60 days prior to launch.

Rehabilitation begins on the day of return to Earth and lasts 45 days. It includes two hours of exercise per day, seven days/week (if needed). Each session includes dynamic warm-up, stretching, core and trunk stability, flexibility, and cardiovascular training. Post-flight performance testing is assessed seven and 30 days after return to Earth.

Goals of the program include the following:

Pre-flight:

- Optimize strength, endurance, flexibility, power, coordination, stamina.
- Focus on areas of concern.
- Familiarize astronauts with inflight exercise hardware, injury prevention, and teach proper technique for use of hardware.

In-flight:

- Protect crew health by minimizing losses in strength, endurance, flexibility, and bone mineral density.
- Maximize reconditioning.
- Lower body exercises are performed daily focusing on loading bone at the hip to decrease resorption.
- Upper body exercises are performed every other day.

Post-flight:

- Aerobic and anaerobic training focuses on improving deficits in strength, power, endurance, agility, balance, stamina, and coordination.

- Crewmembers have unique deficits that require personally tailored exercise programs to return them to their baseline as quickly and safely as possible.
 - Much of the initial exercise is performed in water.

1200-1300: Working lunch: Review of intervertebral disc research results in U.S. astronauts

This information is covered in the background information and cervical lecture on day two.

1315-1415: Evaluate current pre-, in-, and post-flight injury prevention and treatment strategies among U.S. astronauts – Presented by Richard A. Scheuring, DO

Dr. Scheuring discussed two cases, which occurred after the 2015 NASA Low Back Pain Summit, of mission assigned astronauts who developed pre-flight lumbar spine injuries months before their spaceflight. In each case, there was no knowledge of underlying spine pathology prior to the injury. Non-contrasted lumbar spine MRI was obtained as clinically indicated, confirming clinical suspicion of multilevel degenerative intervertebral disc (IVD) disease, facet hypertrophy, and, in one case, single level HNP with neural foramina narrowing and nerve root effacement with resultant radiculopathy. Each astronaut was aggressively treated according to the current standard of practice for their condition. In addition, consultation with orthopedic and neurosurgery specialists helped guide the diagnosis and treatment decisions. Additional consultation with the crewmembers' flight surgeons and ASCR specialists prompted re-assessing the pre-flight strength and aerobic conditioning program. Alterations in the conditioning program were made to limit spinal and lower extremity loading during the acute convalescence phase but maintain cardiovascular tone and flexibility, consistent with current spine rehabilitation practices. Weight offloading treadmills, utilizing water and differential air pressure, are examples of exercise devices that were utilized for this phase. Each astronaut was gradually returned to full pre-flight exercise training status within six weeks of the onset of symptoms. The on-orbit conditioning program was modified for each crewmember considering pre-existing disease and ways to prevent re-injury. Both astronauts were able to complete their six-month duration mission without recrudescence of symptoms. Post-flight MRI imaging was remarkable for near complete resorption of IVD nucleolus pulposus at the pre-flight affected vertebral levels. Post flight reconditioning emphasized stretching and core stabilization exercises, with gradual return of loading and agility skills. Dr. Scheuring concluded that these two cases illustrate how knowledge of existing pre-spaceflight spine pathology and alteration of the required astronaut resistive and aerobic conditioning program in all mission phases can prevent recurrence of injury and possibly prevent acute exacerbation of existing asymptomatic disease in affected astronauts.

1415-1500: Best practices for back rehabilitation in terrestrial populations – Presented by Danny Keller, PT, DPT, OCS and Kenny Leung, PT, DPT, OCS, CSCS

As discussed previously by the IVD Research Group, multifidus atrophy and fat infiltration appear to be correlated with chronic low back pain. Research shows that some of these changes can be reversed through improving function and strength through physical therapy. To best approach this, it will be necessary to design a functional test that assesses the multifidus and a movement screen to try to predict if someone will have pain.

To target the multifidus, it is necessary to understand its role and how dysfunction is manifested. The multifidus decreases shear force on vertebral bodies. When dysfunctional, the increased shear force results in larger amounts of tension on the annulus, resulting in dysfunction in the intersegmental stability of the spine. The deep fibers of the multifidus are involved in intersegmental motion and stabilization, whereas the superficial fibers are more involved in spinal orientation. Multifidus counters the flexion force of the oblique muscles in rotational movement.

Terrestrially, fat infiltration of the multifidus is manifested by asymmetric firing patterns, delayed firing of the multifidus, increased paraspinal tone, and instability of spinal movement patterns. Selective training of the lumbar multifidus and transverse abdominus musculature can restore spinal stabilization.

Strength can be measured in the multifidus using a single leg bridge hold or a side plank or plank with a push/pull with a cable. This could be done pre- and post-flight.

There is no evidence supporting a single best stability exercise. A combination of segmental and global training has been found to be the most beneficial. It is important to include abdominal musculature, quadratus lumborum, the pelvic floor, and the diaphragm. These muscle groups work in concert to improve intra-abdominal pressure and create spinal stability. They all need to be addressed together. Transverse abdominis atrophy (with concurrent compensatory hypertrophy in the internal oblique) is common in chronic low back pain. Quadratus lumborum is more active in chronic low back pain, likely due to poor timing of activation of the remaining musculature. Pelvic floor muscle stability is felt to reduce low back pain and support better trunk muscle activation. Diaphragmatic breathing is felt to improve low back pain as well.

It is recommended that physical therapy for back pain include strength, form, stability, and coordination as measurable variables to track progress and exercises be tailored to the individual. Incorporating massage and manual therapy immediately before PT exercises is beneficial. Pre-flight exercises outside the sagittal plane should be included that perform higher loads. Whenever possible these exercises should be like exercises performed in-flight and task specific. They should build on previous exercises done by the individual, identify movement dysfunction with screening tools, and reinforce movement and timing concepts. Post-flight exercises should reduce pain, and gradually improve function, stability, form, strength, and coordination to baseline. There may be a benefit to allowing this to occur over a longer timeframe than the current protocols.

1500-1520: Future in-flight exercise devices – Presented by John DeWitt, PhD

Three categories of future long-duration missions are in development. Exploration Mission 1 (EM1) will involve sending an unmanned Orion capsule. Exploration Mission 2 (EM2) will be a manned test of an Orion capsule. Exploration Mission 3 (EM3) will involve Deep Space Gateway Missions. On these missions the Orion capsule will travel to Deep Space Gateway,

which is in a lunar orbit. Approximately 30-45 days will be spent at the Gateway habitat prior to returning.

By the 2030s the goal is to send manned missions to Mars, which will require humans to live in space for approximately four years. It is necessary to prepare exercise countermeasure equipment for these vehicles now in preparation for interplanetary travel. The current prototype device for the Orion capsule is a very small flywheel device. The Gateway vehicle will be much larger than Orion but smaller than ISS.

The current plan is to send an all-in-one device to Gateway that includes the capabilities of ARED and CEVIS, maintaining the current standard of up to 600 pounds of resistive training as well as cardiovascular conditioning. A treadmill is not planned to be sent to Gateway because it is too large. Should commercial habitats allow room for a treadmill, then a successor of T2 will be sent to Gateway. It is anticipated that this will not be the case.

Rather, a rowing device is being designed for Gateway. One challenge with the creation of this device will be creating a vibration isolation system to prevent impact forces from traveling into the structure of the Gateway vehicle. Additional challenges include: improving upon the device capabilities currently available on ISS in a smaller, all-in-one structure, and adding rotational core exercise capability.

The European Space Agency (ESA) and NASA are independently developing an all-in-one rowing device. Functional testing will take place at Johnson Space Center to determine which of the two prototypes will be included in Gateway. Notably, no ground testing is planned to take place. The assumption is being made that if the device is equivalent in capability to ARED and CEVIS then it will accomplish the desired effect. The device will be placed in the astronaut gym to allow for feedback from the crew and for training purposes for long-duration missions.

In 2020, the rowing device will be sent to ISS and remain there for the lifetime of the ISS program. U.S. astronauts will be assigned to exploration class mission simulations in which they only use exploration hardware to test the efficacy of the rowing device in space.

1520-1620: Discussion and Recommendations

See Appendix 1 for finalized summary of recommendations.

1620-1700: Recommendations Summary

See Appendix 1 for finalized summary of recommendations.

APPENDIX 3: DETAILS OF AGENDA – DAY TWO

Spine Workshop, January 26, 2018

Day 2 Agenda:

0800-0900	Background and summary of recommendations from Day One Short introduction from Alan Hargens, PhD
0900-0940	Update on Intervertebral Disc Cervical Work
0940-1020	Overview of in-flight IVD ultrasound study
1020-1100	Overview of in-flight spinal lengthening study
1100-1130	Assessing/Screening spinal muscle function - Russian Experience
1130-1200	Role of the vertebral endplate pathology in low back pain and spine disorders
1200-1300	Break for lunch
1300-1500	Future directions and countermeasures for the spine <ul style="list-style-type: none">• Countermeasures and screening measurements• Discussion of the value of possible in-flight muscle ultrasound study• Supporting future validations studies• Pre-flight paraspinal muscle training guidelines

Details of Sessions:

0800-0900: Background and summary of recommendations from Day One. Short introduction from Alan Hargens, PhD.

This included a summary of Day One. Alan Hargens, PhD provided an overview. Jeannie Bailey, PhD and Jeffrey Lotz, PhD briefly summarized their IVD research again. Note that some participants were not at the workshop both days, thus the repetition of salient research. See Appendix 1 for finalized summary of recommendations.

0900-0940: Update on Intervertebral Disc Cervical Work – Presented by Doug Chang, MS, PhD, MD

Dr. Chang presented evidence from some studies focusing on deep cervical flexor and extensor musculature showing that fat infiltration and muscle atrophy have been associated with painful neck syndromes.

Unique to the cervical spine is its role in the ocular-vestibular system. This is a large area of research for the cervical spine and focuses on proprioceptive adaptations that can lead to spatial disorientation, or issues with posture and head/trunk coordination during readaptation to a terrestrial environment after spaceflight. This has operational significance. Cervical spine pain could affect functional mobility, including impacting mission integrity by minimizing the ability of a crewmember to explore a planetary surface, or perform emergency egress.

In the intervertebral disc research group study, preliminary data showed, like the lumbar spine, that cervical paraspinal muscles had a decreased FCSA of approximately 17%. However, the recovery process for the cervical spine was much longer than the lumbar spine. It should be noted that the data was incomplete, so this has presented a challenge in its interpretation. The group is still assimilating the data.

Future directions of this research include a repeatability study to quantify measurement uncertainty and expand the research to include more crewmembers. Countermeasures for the cervical spine could include the neck extensor endurance test and cranial cervical flexion test (both of which have been verified and validated), yoga concepts, and isolating different cervical muscles in a multiplanar fashion with minimal equipment requirements.

0940-1020: Overview of in-flight IVD ultrasound study – Presented by Michael Harrison, MD, PhD

The objectives of this study were to develop a reproducible methodology for spinal US imaging in space, and to compare the accuracy of these images to pre- and post-flight MRI imaging.

Study Design

Seven U.S. astronauts completing six-month ISS missions were selected for the study. Pre-flight they underwent MRI and US imaging of the spine. In-flight US imaging was repeated on days 30 and 150. Post-flight both MRI and US imaging were repeated. The astronauts received 90 minutes of training prior to launch and just-in-time refresher training on ISS prior to capturing US images.

Results

Overall the astronauts obtained high-quality US images in less than 60 minutes on ISS. In-flight US images and their comparisons to terrestrial MRI images illustrated that the in-flight images could be used to exclude significant spinal abnormalities. A statistical correlation between US and MRI images corroborated this correlation. The US images were able to identify lumbar spine offloading and a trend towards increased height, whereas the cervical spine images showed decreased disc height in-flight. There was one session that contained some missing information at the extremes of a spinal segment (*i.e.* where the cervical and thoracic vertebrae meet, and where the thoracic and lumbar vertebrae meet).

Every subject reported back pain during the mission. Some also experienced post-flight back pain and three subjects required clinical follow-up.

Limitations

The sample size of this study (seven) was very small. The anatomy was diverse between subjects and the exam was non-focused. The US images were also difficult to acquire, and some had poor resolution.

Conclusion

Symptom guided US imaging could be performed for the spine on ISS.

1020-1100: Overview of in-flight spinal lengthening study – Presented by Sudhakar Rajulu, PhD and Karen Young, BS

Dr. Rajulu presented data on seated height change and noted that the increase is felt to be due to spinal elongation in microgravity.

Karen Young, BS presented data from a study completed in 2013 that examined stature change in shuttle and ISS crewmembers for Orion design planning. Orion has a stacked seated configuration, so in-flight seated height change could impact the landing fit.

Study Design

The commander seat from the final shuttle missions was modified for the study. An anthropometer was attached to the seat and the lap belt was altered to eliminate any floating effects. Data was collected from 32 crewmembers of both standing and seated height.

Results

Maximum growth averaged 6% (6.5cm). One crewmember experienced 7% growth. There is a 2:1 ratio of seated height to standing height growth (e.g. 8% increase in seated height is a 4% increase in standing height). Most subjects experienced between 2-6cm of seated height growth and 2-4cm of standing height growth.

Conclusion

It is recommended that any seat design include room for 6% growth in seated stature and standing designs allow for 3% growth in stature in microgravity.

1100-1130: Assessing/Screening Spinal Muscle Function – Russian Experience. Presented by Ilya Rukavishnikov, MD.

Increasing height in space is problematic because it increases risk of trauma during landing. There is very little information on cosmonaut spinal pain. In a paper published in the 1970s, Orlan suits were deemed to help prevent back pain and growth during spaceflight. Since the beginning of Russian spaceflight, cosmonauts have been experiencing 1-1.5cm of growth in microgravity (like their bedrest studies). One cosmonaut is documented to have grown 7cm in-flight. He was measured immediately post-flight, at the landing site, and found to be 5cm taller than pre-flight. These measurements are obtained with a special measurement device the Russians have on ISS that measures from the occiput to the base of the lumbar spine.

The Russians have experienced SABP just as the Americans have. Russian theories for the etiology of back pain in space include: microgravity, axial unloading, support unloading, intervertebral disc height increases, loss of lumbar lordosis, vertebral column lengthening, and atrophy of spinal musculature.

They use a dry immersion model to simulate the microgravity changes experienced by the spine in space. With this model, coupled with bed rest, they simulate axial unloading, support unloading, cranial fluid shift, and body height increase. Older studies they performed showed a sharp initial decrease in muscle activity in the first few hours, that plateaued and then rapidly improved after removal from the experiment. This was determined to be due to the decreased force on postural muscles with axial offloading.

Russia has done studies with subjects in the dry immersion model for one hour, six hours, three days, and five days. After six hours they have observed 2.4cm of seated height increase and this was associated with a 5-6/10 pain scale rating for muscular lumbar pain, without neurologic involvement. There was also increased transverse abdominis muscle stiffness measured with a myotonometer and vibration. Most of the changes seen in the spine with dry immersion are in the lumbar region. At three days of dry immersion there was a strong correlation between back pain intensity and body height increase and muscle atrophy. After five days of dry immersion, lumbar lordosis was decreased, disc size increased significantly at L-3, L-4, and L5 levels, and muscle atrophy was seen.

Field tests have also been used to measure muscle tone within 30-40 minutes of Soyuz landings. They demonstrated significant decreases as compared to pre-flight data.

The Russians have unique countermeasures. They have an axial loading suit that cosmonauts use to reportedly prevent pain and height increase. Prior to landing they also run for 30 minutes to enhance fit in their custom seat in the Soyuz capsule.

The Russians perform pre- and post-flight MRI surveillance.

The Russian experience corroborates the American experience of in-flight back pain. They believe we are discussing the same physiologic adaptation syndromes to microgravity.

1130-1200: Role of the vertebral endplate pathology in low back pain and spine disorders

See presentation from Dr. Lotz on day one.

1300-1500: Future directions and countermeasures for the spine

See Appendix 1 for finalized summary of recommendations.

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