Cervical Spine Intervertebral Disc Herniation on board the International Space Station: Diagnosis, Treatment and Operational Mission Impact

Richard A. Scheuring, DO, MS, RMSK, FAsMA
Rainer Effenhauser, MD, MS
Lt Col Danielle N. Anderson, DPT, DSc
Mark Vande Hei, COL (ret.), US Army
NASA-Johnson Space Center
Paul Holman, MD
Dept of Neurosurgery, Houston Methodist Hospital
COL Mel Helgeson, MD
Dept Of Orthopedic Spine Surgery, Walter Reed National Medical Center

AOCOPM
22 MAR 24

Disclosure Information

Richard A. Scheuring, DO, MS

- We have no financial relationships to disclose.
- We will not discuss off-label use and/or investigational use in our presentation
- Views presented are our own and do not reflect the views of NASA, the US Government, DoD, or USUHS…

93rd Anniual Aerospace Medicine Scientific Meeting, New Orleans, LA
24-May-2023

Overview

- A healthy RHD 55-year-old astronaut has developed an acute right-sided neck pain extending into the right arm with paresthesia and weakness four months into his long duration space flight on the International Space Station (ISS)…
  - You're 24 hours from going out the hatch for a planned PET 7:00 Extravehicular Activity (EVA)
  - How do you make the diagnosis?
  - What are your treatment options?
  - What do you tell the NASA chief medical officer (CMO), mission planners, flight directors, crew member's family, and ISS Program managers?

Start of USOS EVA 45 during ISS Exp 53 10-Oct-2017.
Source: iss053e095650.jpg @ nasa.gov.

Overview

- There was no prior h/o cervical spine issues in this individual
- At the time of mission assignment, there was no requirement for spinal imaging for screening purposes
- Prior to the gradual onset of symptoms, crew member had been performing all required on-board activities and exercise
- There was no apparent mechanism of injury (MOI) on the ISS

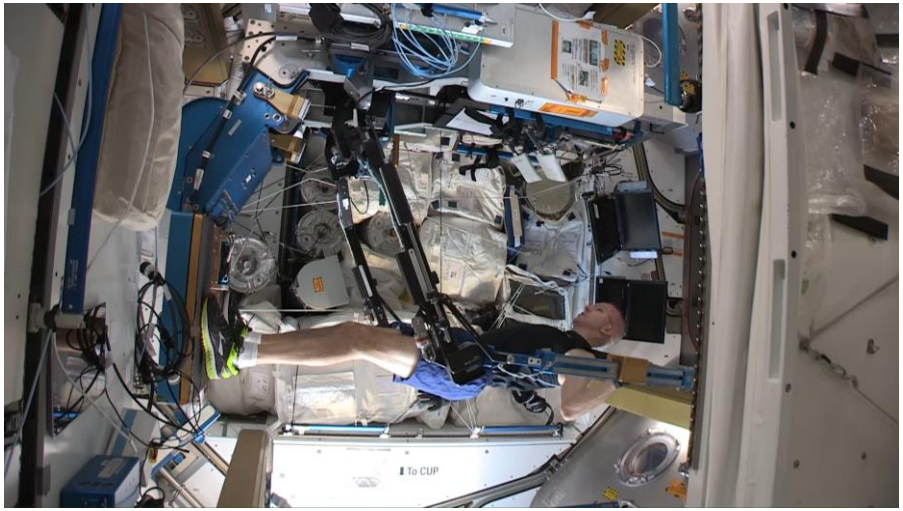
Overview

- Human space flight poses unique challenges to the diagnosis, treatment, and monitoring of medical conditions
  - Discuss Diagnosis & Treatment
  - Operational Mission Impacts
  - On-orbit Musculoskeletal (MSK) Rehabilitation
  - Spinal Pathophysiology
  - Disposition

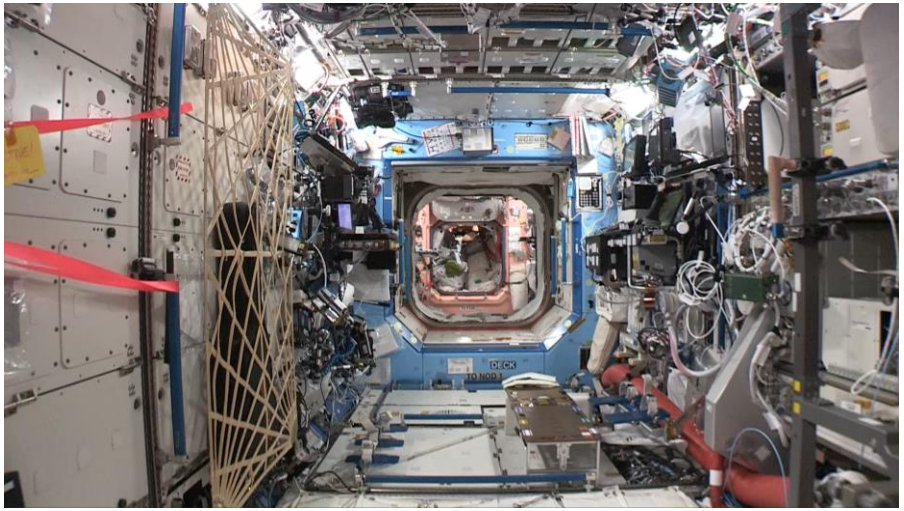
64S…

- 9 April 2021- Launch

Primer on On-Orbit Exercise Countermeasures



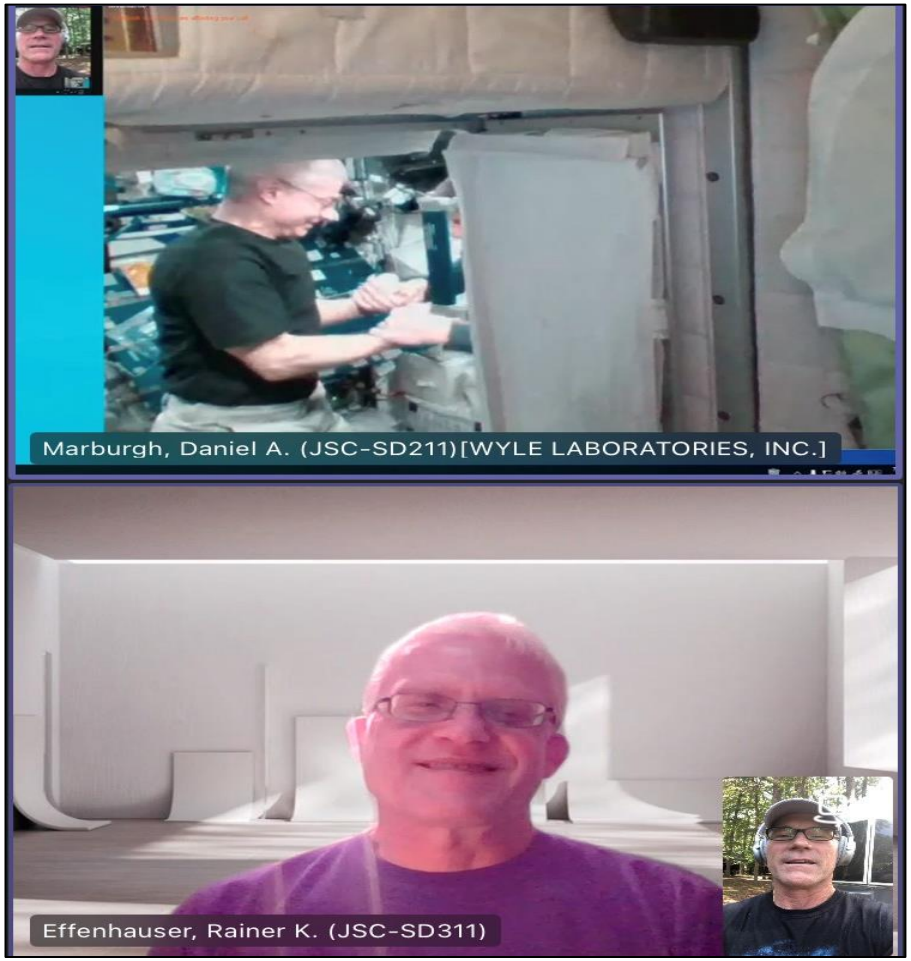
ISS Exp 53 CDR Randy Bresnik demonstrating **ARED** Exercises on ISS, November 2017



ISS Exp 53 CDR Randy Bresnik demonstrating running on the "**T2**" treadmill in Node 3, ISS, November 2017.

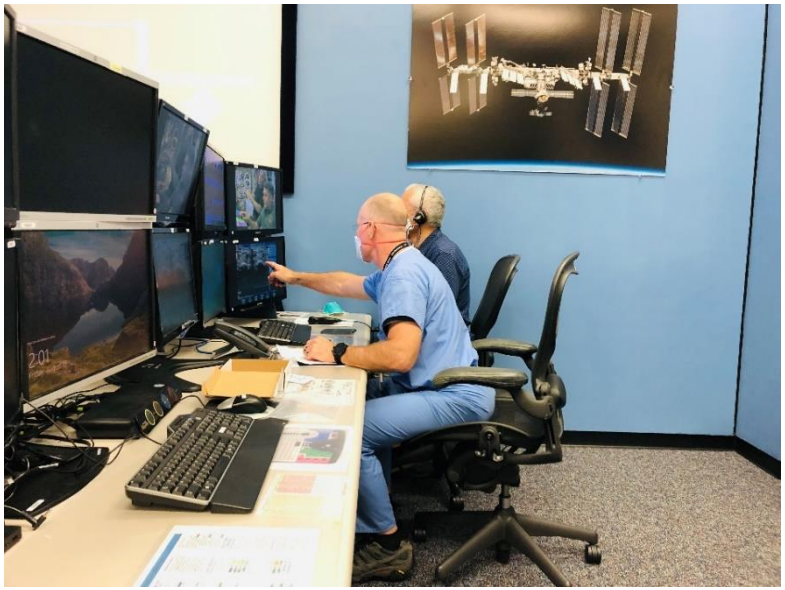
Diagnosis & Treatment

- June 2021- Onset mild right medial elbow pain with grabbing hand holds during translation
  - Differential diagnosis
    - Medial epicondylitis
    - Common flexor tendon strain
    - Ulnar collateral ligament sprain
    - Ulnar nerve subluxation
    - Cubital tunnel syndrome



Remote Audio-Visual Private Medical Conference (PMC) via Teams

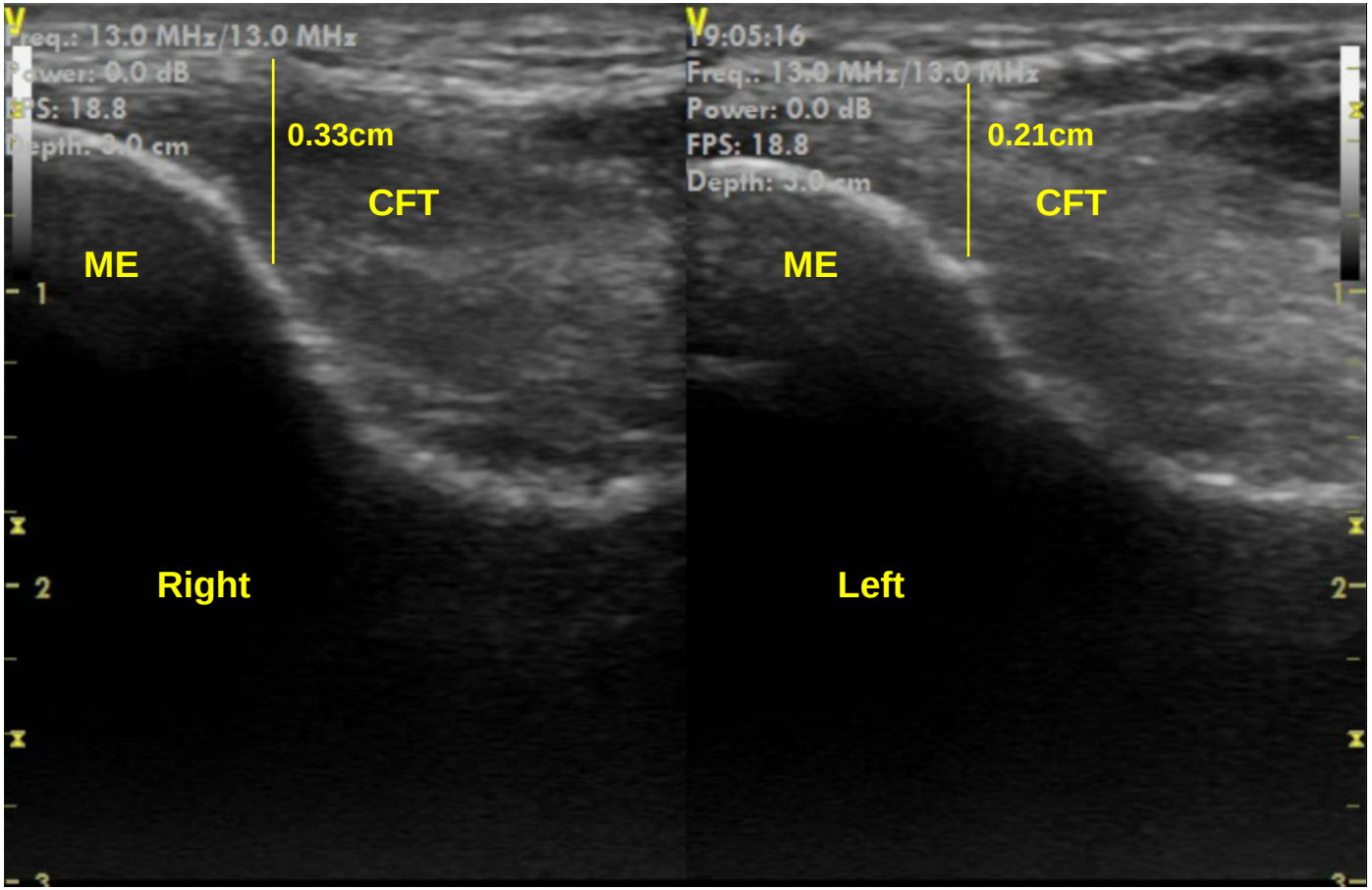
Diagnosis & Treatment



NASA-JSC Telemedicine operations center, Mission Control Center, Houston, TX

Remotely guided MSK Ultrasound of the right medial elbow

MSK Ultrasound from ISS



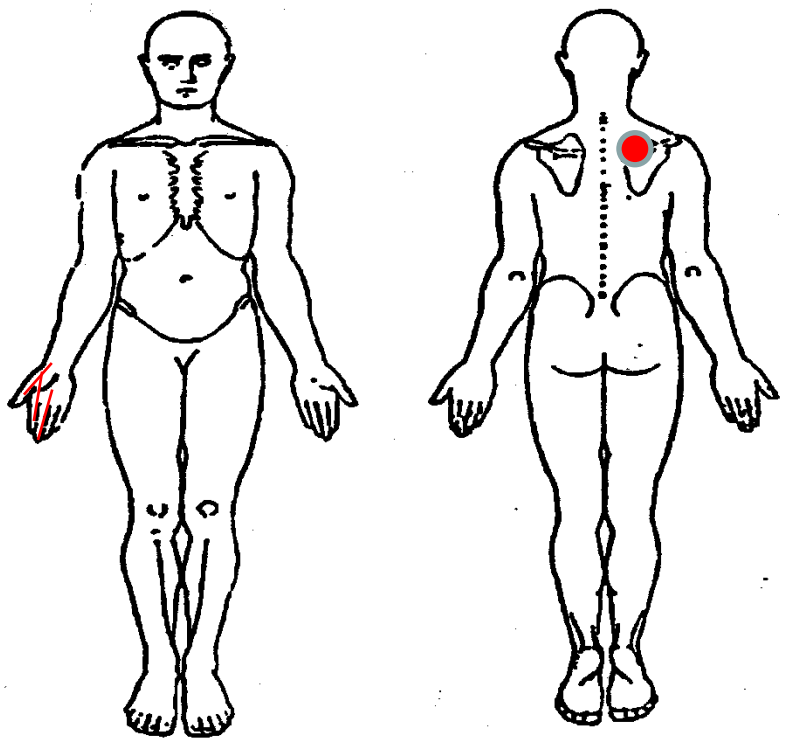
Comparison long axis view (LAX) US medial epicondyle (ME) with common flexor tendon (CFT) swelling and hypoechoic changes in CFT near the enthesis consistent with moderate medial epicondylitis

Initial Treatment for Medial Epicondylitis

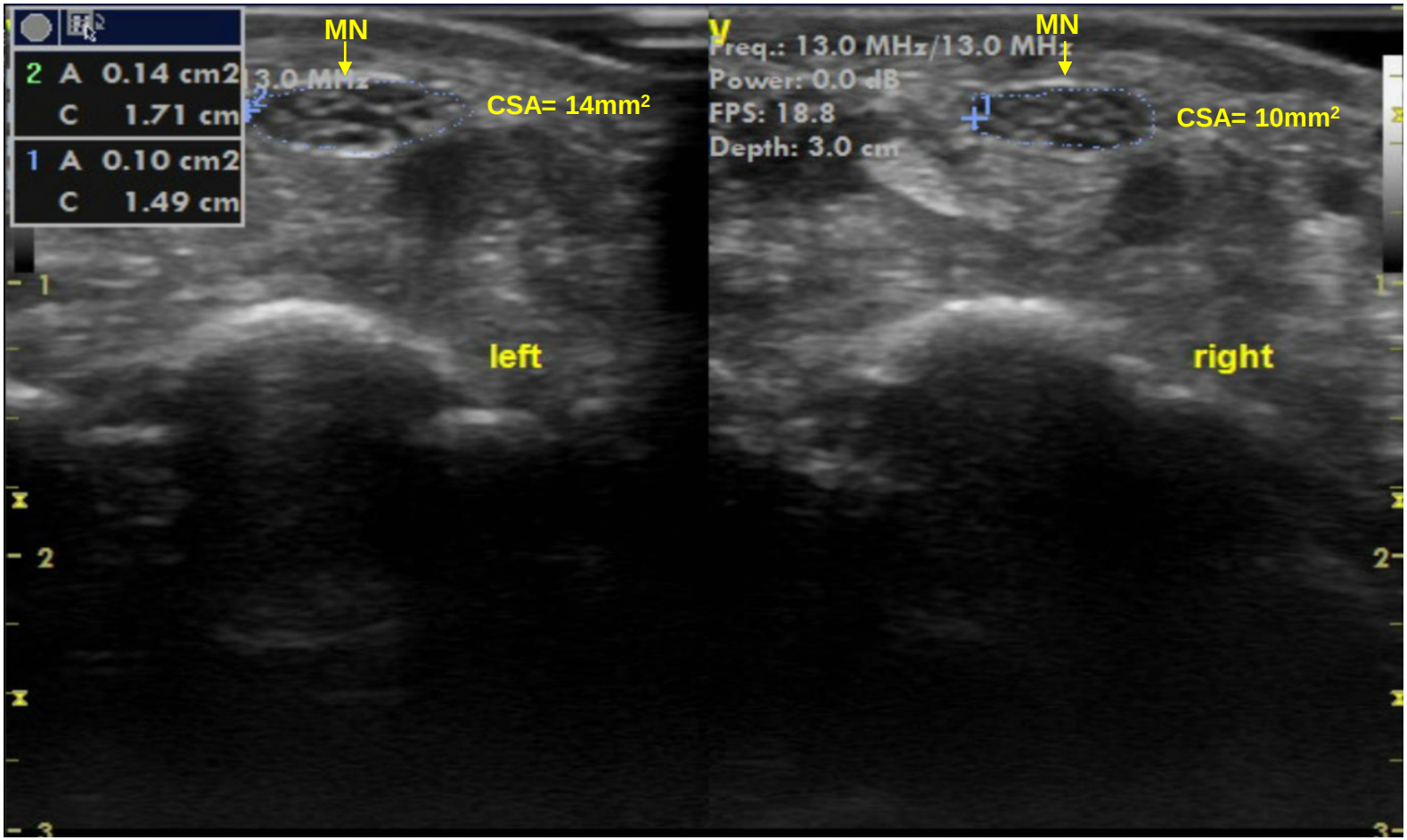
- Rx w/ topical diclofenac gel 1%, relative rest/exercise and activity modification; Frequent comms/status via email, PMCs, Private Exercise Conferences (PECs).
- Approximately 3-4 weeks after initial diagnosis symptoms were 70-75% improved

Diagnosis & Treatment

- Approximately 4 months into ISS Expedition 64…
  - 1 August 2021- Onset mild R Scapular discomfort
  - 6 August 2021- Onset Paresthesia and numbness of Distal R thumb and index fingers, later tips of Right 1/2/3 fingers.



Median Nerve Evaluation



Comparison short axis view (SAX) US of the median nerve (MN) at the proximal carpal tunnel with cross sectional area (CSA) measurements of both left and right nerves.

Initial Treatment for CTS

- Rx w/ oral steroids, Rest/Exercise Modification; Frequent comms/status via email, PMCs, Private Exercise Conferences (PECs)
- Feedback on 14-Aug was that paresthesia improved, scapular pain lessened, overall improving

Case Progression

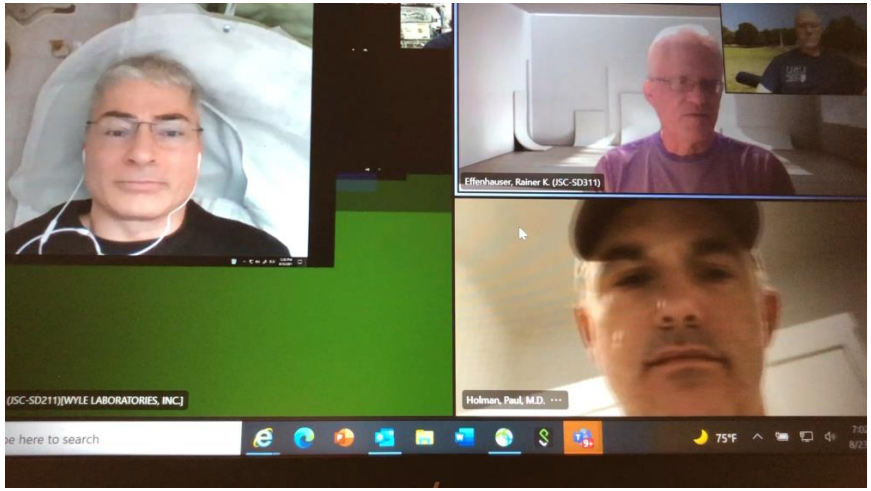
- 20 August 2021- Onset Right Triceps weakness, worsened hand paresthesia; (Notified Surgeon late 22 August):

"I think that on Friday (whatever day involved recording of my ARED session), I noticed while doing Cable Triceps Extensions that my right arm didn't seem to be getting recruited as much as I'd like. Without changing the weight, I used my left arm to see if I could do a rep. I could move the bar a couple of inches. I then tried with my right arm and couldn't budge it."

DATE	Triceps Extension	Notes
20 August 2022	L: Normal, R: unable	20 lbs.
21 Aug 2022	13 reps L, 2 reps R	20 lbs.
22 Aug 2022	Notified Surgeons of Weakness by email	

Unscheduled Private Medical Conference (PMC)

- 23-Aug-2021 PMC:
  - Realtime neurological exam with our neurosurgical/ortho spine surgical consultants
  - Clinical hx, PEX c/w acute C6/7 HNP with C7 radiculopathy including motor weakness of the triceps

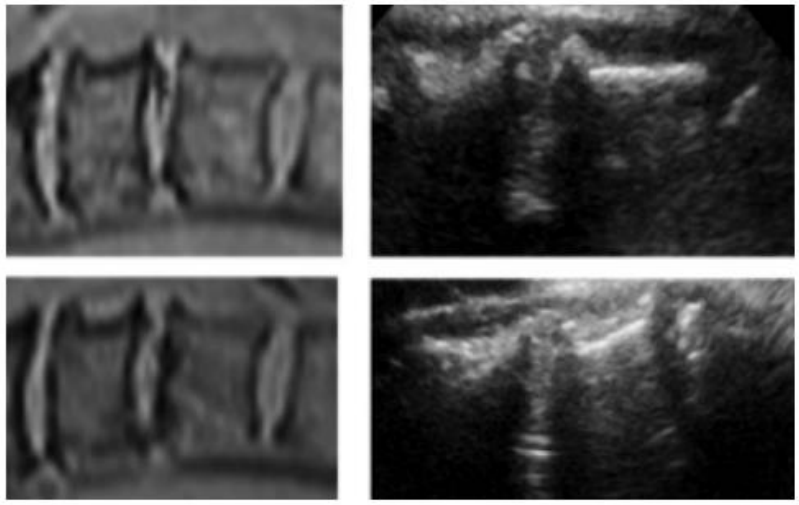


Forward Plan

- Decision to defer participation on 24-Aug EVA
- Begin relative rest, repeat Medrol dose pack, short-acting BZP for muscle spasm, modified exercise program
- Develop on-orbit cervical spine and triceps muscle US procedure

Pioneering Spine Ultrasound in Space

Figure 10. Osteophytes shown before (top) and after (bottom) flight on MRI and US images of the cervical spine in C4–5 and C5–6. The US images look slightly more retracted, but the irregularity remains.



Real-time Ultrasound Assessment of Astronaut Spinal Anatomy and Disorders on the *International Space Station*

Kathleen M. Garcia, BSc, Michael F. Harrison, MD, PhD, Ashot E. Sargsyan, MD, Douglas Ebert, PhD, Scott A. Dulchavsky, MD, PhD

Objectives—Back pain is one of the most common conditions of astronauts during spaceflight and is hypothesized to be attributed to pathologic anatomic changes. Ultrasound (US) represents the only available imaging modality on the *International Space Station*, but a formal US protocol for imaging the structures of the spinal column does not exist. This investigation developed a method of acquiring diagnostic-quality images of the anterior lumbar and cervical regions of the spine during long-duration spaceflight.

Methods—Comprehensive spinal US examinations were conducted on 7 long-duration spaceflight astronauts before flight, in flight, and after flight and compared to preflight and postflight magnetic resonance imaging data. In-flight scans were conducted after just-in-time training assisted by remote expert tele-US guidance.

Results—Novice users were able to obtain diagnostic-quality spinal images with a 92.5% success rate. Thirty-three anomalous or pathologic findings were identified during the preflight US analysis, and at least 14 new findings or progressions were identified during the postflight US analysis. Common findings included disk desiccation, osteophytes, and qualitative changes in the intervertebral disk height and angle.

Conclusions—Ultrasound has proven efficacy as a portable and versatile diagnostic imaging modality under austere conditions. We demonstrated a potential role for US to evaluate spinal integrity and alterations in the extreme environment of space on the *International Space Station*. Further investigations should be performed to corroborate this imaging technique and to create a larger database related to in-flight spinal conditions during long-duration spaceflight.

Key Words—astronaut; cervical spine; lumbar spine; microgravity; musculoskeletal; point of care; spine; sonographer issuer; sports medicine/orthopedics; ultrasound techniques/physics

Received March 24, 2017, from KBRwyle, Houston, Texas USA (K.M.G., A.E.S., D.E.); and Departments of Emergency Medicine (M.F.H.), Internal Medicine (M.F.H.), Critical Care Medicine (M.F.H.), and Surgery (S.A.D.), Henry Ford Hospital, Detroit, Michigan USA. Manuscript accepted for publication July 18, 2017.

We thank the astronauts and the International Space Station Medical Project implementation team members who participated in and supported this project. This research was supported by the National Aeronautics and Space Administration (NASA) through NASA grant NNX10AM34G.

Address correspondence to Scott A. Dulchavsky, MD, PhD, Department of Surgery, Henry Ford Hospital, 2799 W Grand Blvd, Detroit, MI 48202 USA.

Email: sdulcha1@hfhs.org

Abbreviations

ISS, International Space Station; MRI, magnetic resonance imaging; NASA, National Aeronautics and Space Administration; US, ultrasound

doi:10.1002/jum.14438

Starting with the *Apollo* program and continuing with the *International Space Station* (*ISS*), moderate-to-severe back pain has been a consistent and common medical condition among astronauts during the first 10 days of spaceflight.[1–5] Retrospective studies from short-duration *Shuttle* missions have reported up to a 68% incidence of back pain, which peaked within the first 72 hours of microgravity exposure and tended to resolve almost entirely by the 10th day.[3,6] This condition, referred to as space adaptation back pain, has not been reported to adversely affect a space mission and is predominantly described as benign and not associated with long-term morbidity.[1–3] The exact mechanisms of space adaptation back pain are not well understood, largely because of the lack of in-flight

J of Ultrasound Medicine, Volume: 37, Issue: 4, Pages: 987-999, First published: 29 September 2017, DOI: (10.1002/jum.14438)

Procedure development

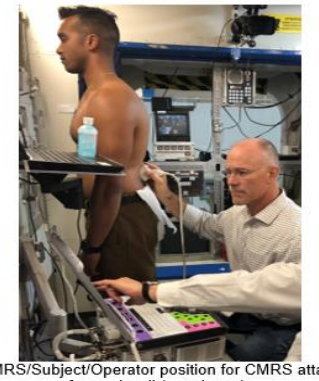


Figure 3.- Alternate CMRS/Subject/Operator position for CMRS attached to seat tracks on forward wall (not shown).

Position CMRS against forward wall and attach to seat tracks (Figure 3)

1.3 Configure restraint device(s) of choice if desired (i.e., foot loops, bungees, CMRS, etc.) in preparation for maintaining stability of subject and operator during scan. Restraint configuration should prevent any spinal movement of the subject to avoid inadvertent contraction of the back musculature during the scan unless directed by remote guider.

2. INSTALLING ULTRASOUND 2 PROBE

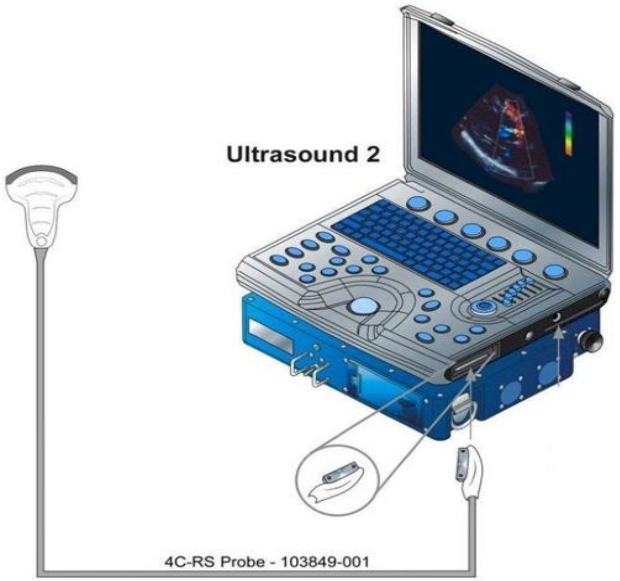
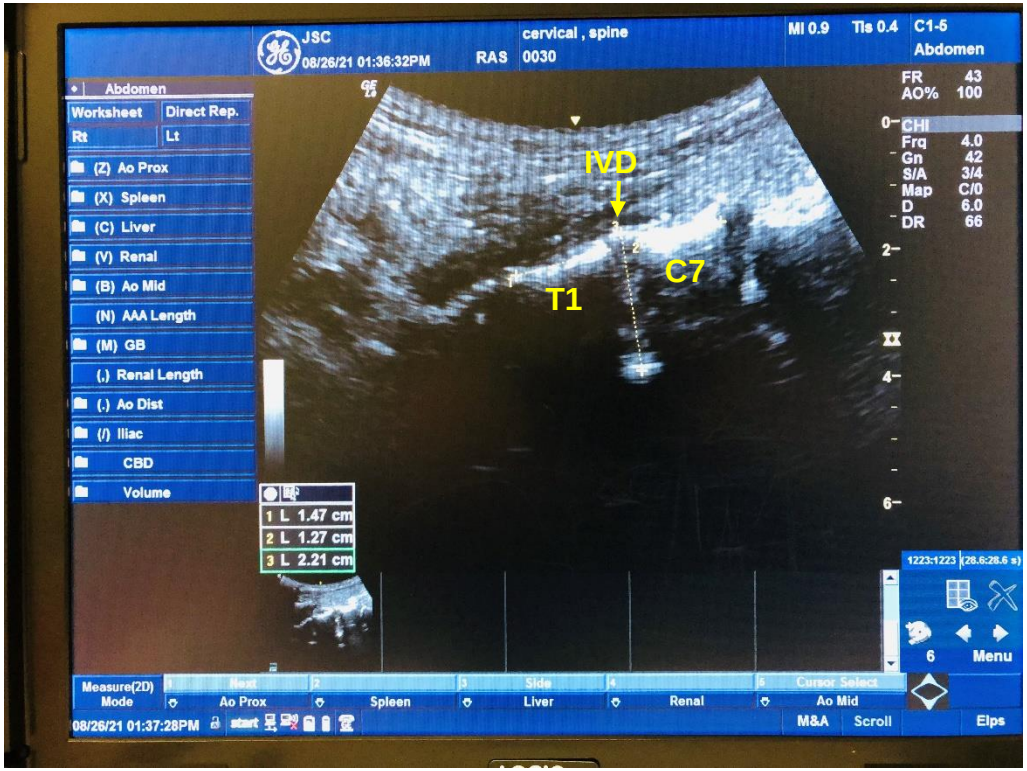
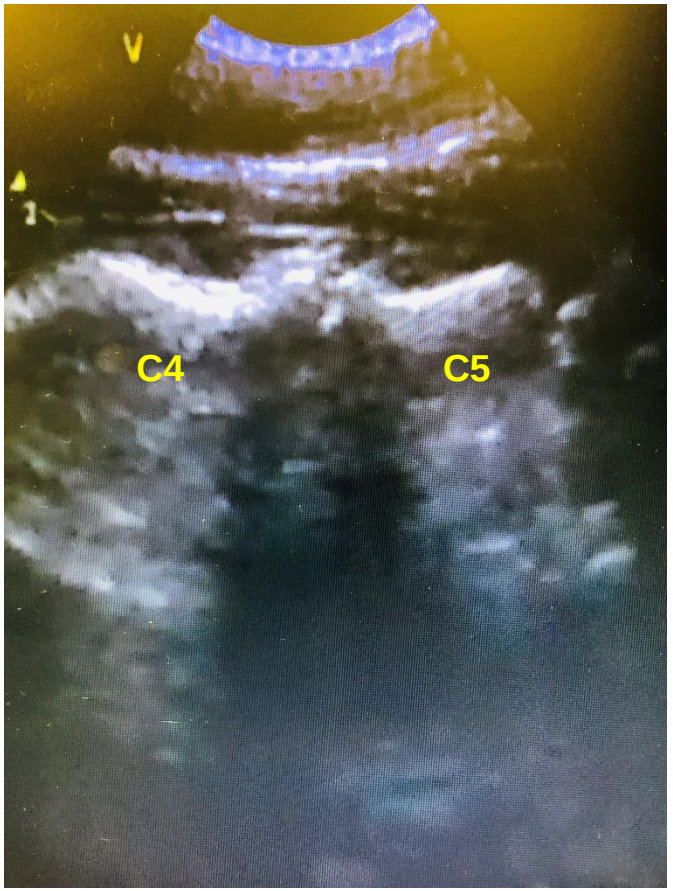


Figure 4. – 4C-RS Probe Cabling Diagram.

Cervical Spine US on ISS

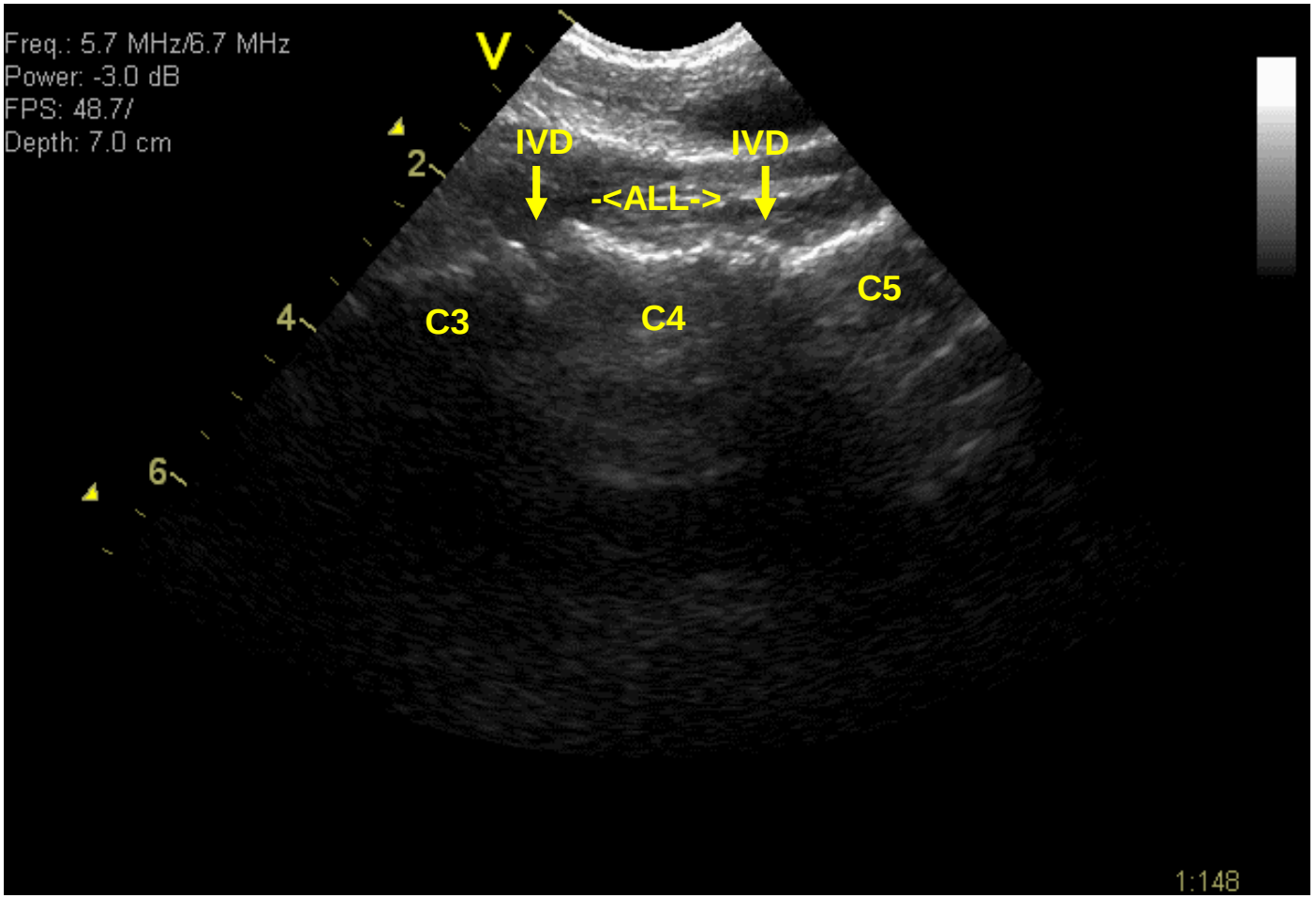


Cervical spine US procedure development and verification at NASA-JSC, 26-Aug-2021



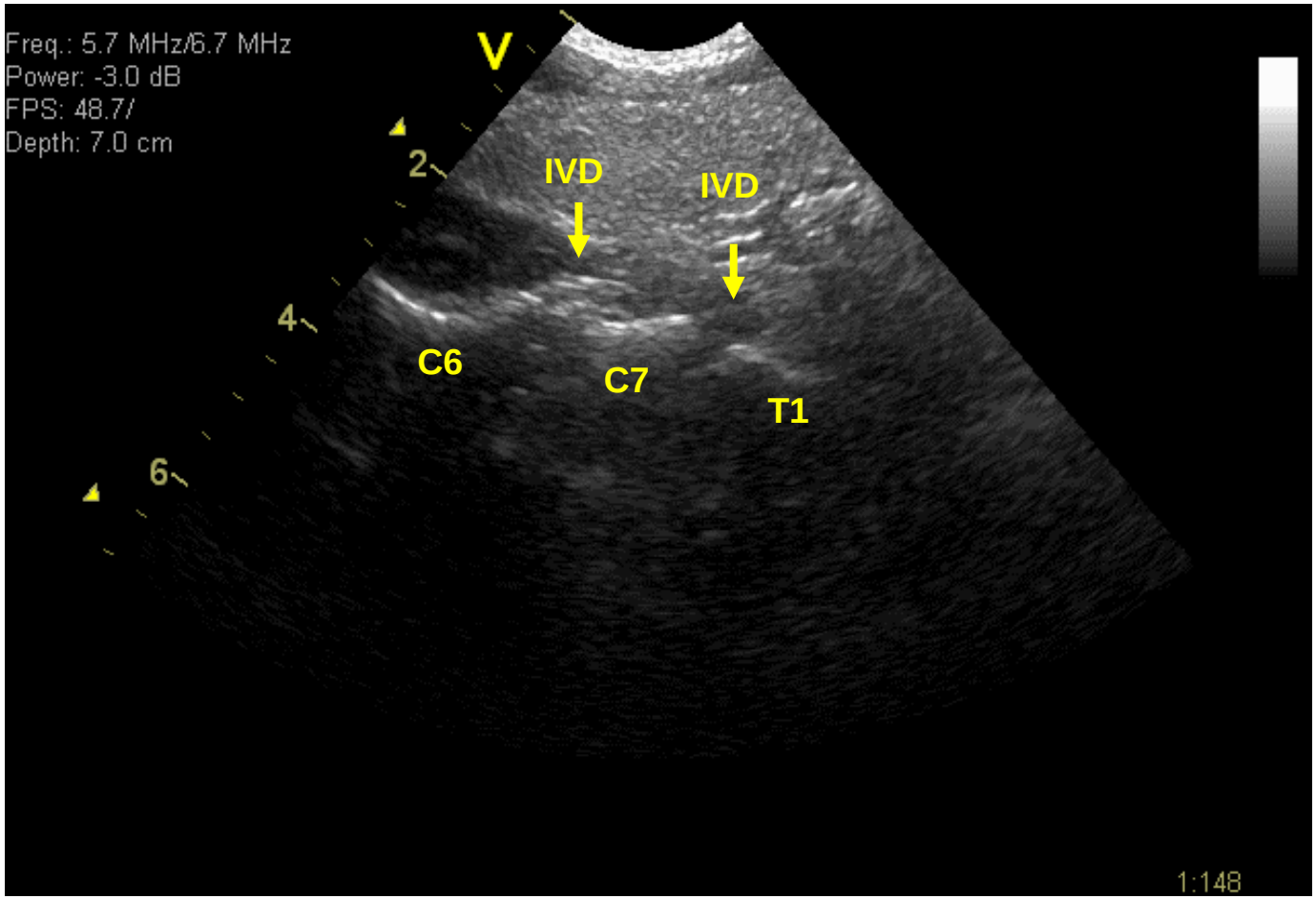
Cervical spine US procedure execution on ISS, 27-Aug-2021 in Columbus module. Image of C4/5 in LAX.

Cervical Spine US on ISS



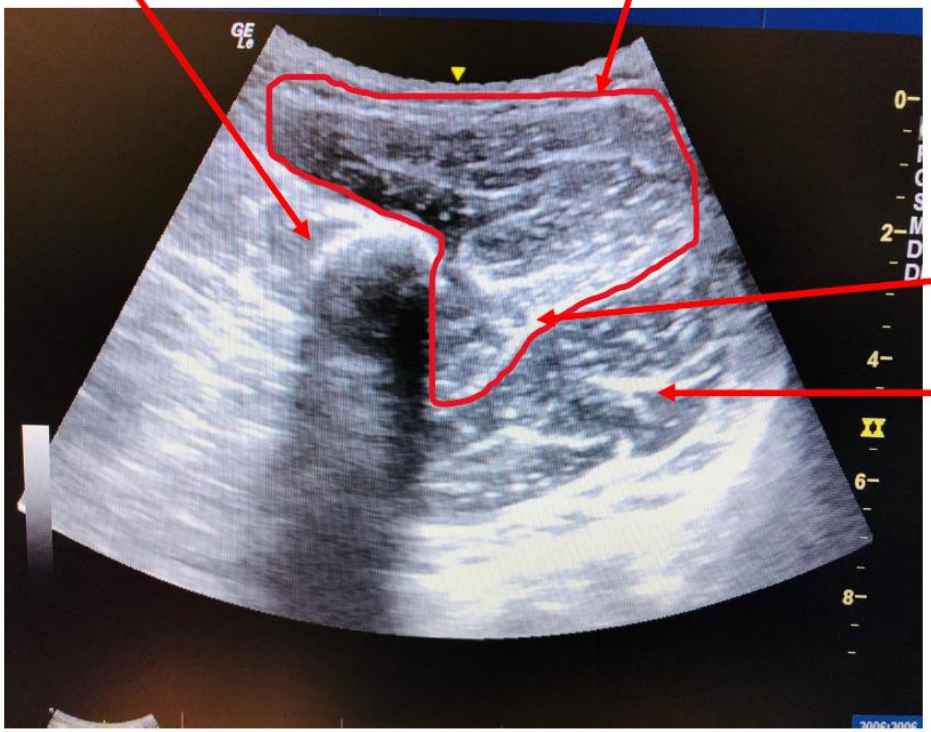
US scan of C4/5 and C5/6 in LAX, 27-Aug-2021.

Cervical Spine US on ISS *cont'd...*



US scan of C6/7 and 7/T1 in LAX, 27-Aug-2021.

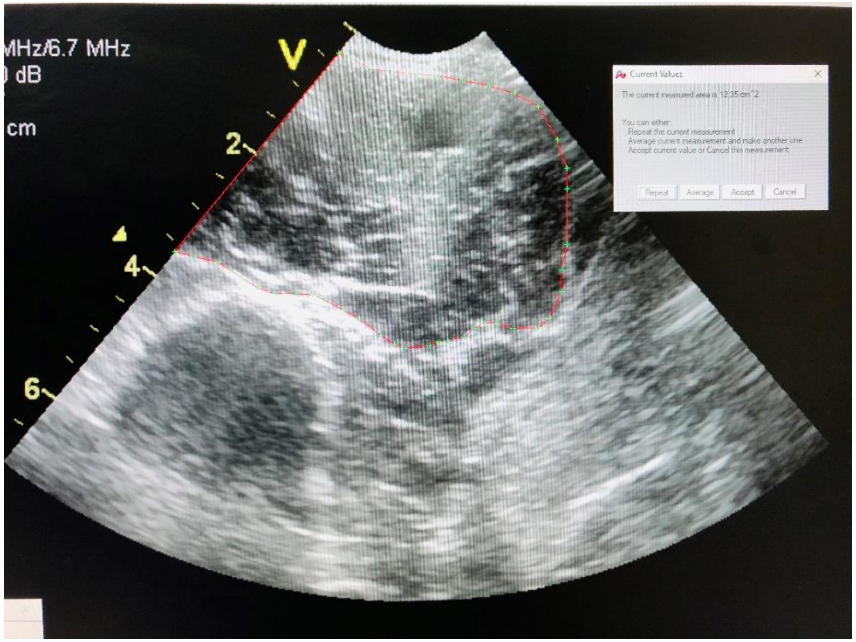
Procedure development



- **This is the image we want to try and capture at the muscle belly**

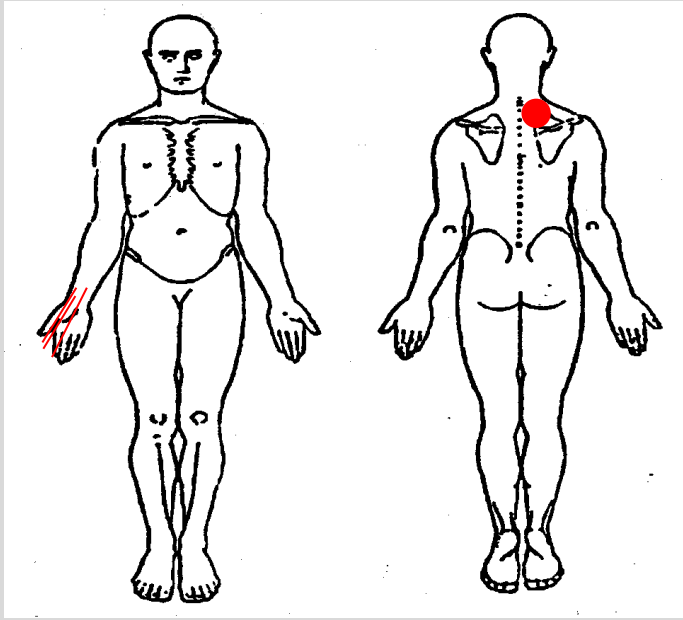
Triceps Evaluation

- Baseline triceps muscle measurements taken with left side comparison views



Clinical Examination

55 y/o male w/sharp scapular pain and numbness/tingling in to the 1-3rd digits



Key Subjective Findings:

- **P1 (scapular pain) present with shaving**
- **P2 (N/T in 1-3rd digits) increases with axial loading**
- **Notable weakness in the right triceps muscle when performing ARED**
- **Reported Right external Jugular vein swelling**
- **Previously pain in medial elbow and intermittent N/T in the 4th and 5th**

Young IA, Phys Ther, 2010

Evidence Based Strategies

Diagnostic Confidence:

- Positive for all 4 test on Wainner Clinical Prediction Rule for Cervical Radiculopathy (Wainner, et al. 2003)
- Key Treatment factors: resolution of symptoms with left cervical rotation, cervical distraction, and cervical retractions against resistance

Number of Positive Criteria	Sensitivity	Specificity	Pos LR	Neg LR
Two	0.39 (0.16-0.61)	0.56 (0.43-0.68)	0.88 (1.5-2.5)	1.09
Three	0.39 (0.16-0.61)	0.94 (0.88-1.0)	6.1 (2.0-18.6)	0.65
Four	0.24 (0.05-0.43)	0.99 (0.97-1.0)	30.3 (1.7-538.2)	0.77

Treatment Approach:

- Initial Goals: Resolution of symptoms utilizing exercise in the direction of easing positions
  - AAROM in to left rotation, scalene stretching, cervical retractions progressing resistance
- Longer term goals: Normalize mobility, sensation and strength
  - Progressive mobility and loading through ARED of the upper extremity


EXPEDITION
66

SCHEDULE IMPACTS

- Any major changes to crew activity can cause significant changes to the pre-planned events and a create a large replanning effort across the Program
- Medical Impacts to Timeline, such as Mission Impact PMCs for medical issues can lead to cancellation or delay of critical activities such as Extra-Vehicular Activity (EVA)/Spacewalks
- Crew Scheduled vs. Actual Work time is carefully tracked and monitored

Clinical Case Status Aug. 2021

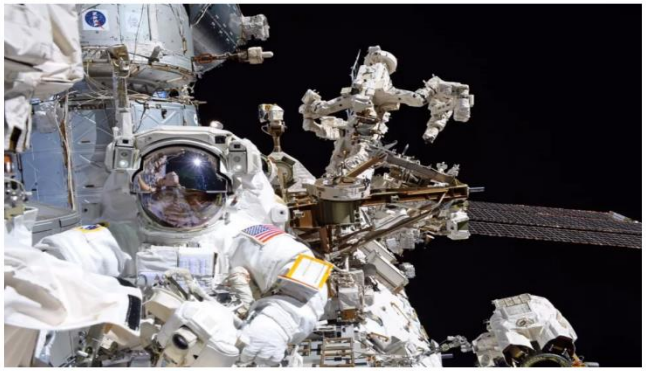
-
-

SPACE.com Subscribe

Astronaut medical issue forces NASA to call off spacewalk at space station

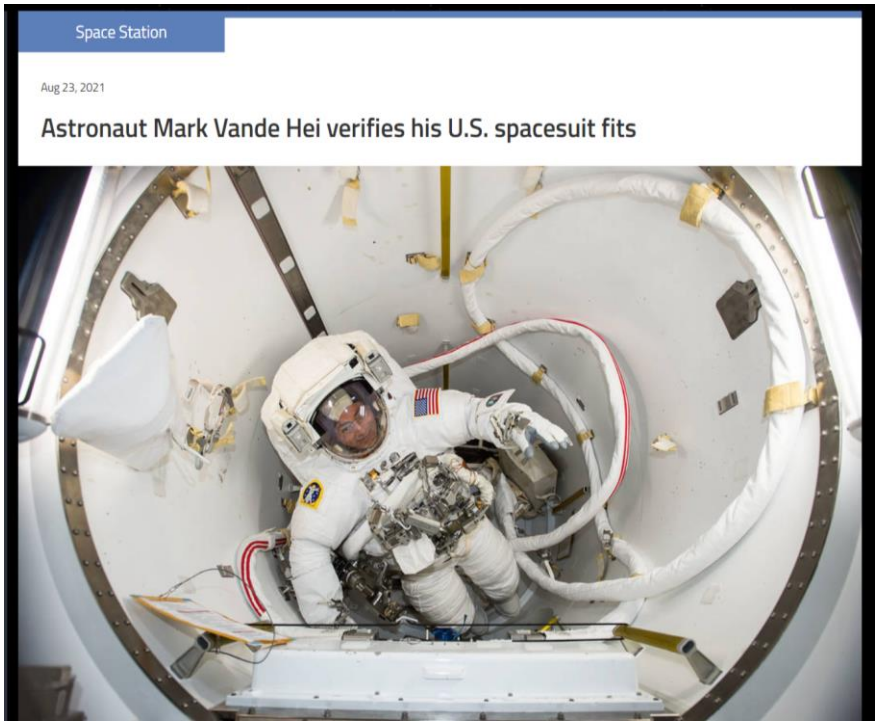
By Tariq Malik 5 days ago

The "minor medical issue" is not an emergency, NASA says.



NASA astronaut Mark Vande Hei on a spacewalk outside the International Space Station in 2017.
(Image credit: Randy Bresnik/NASA/Twitter)

NASA has called off plans for a spacewalk outside

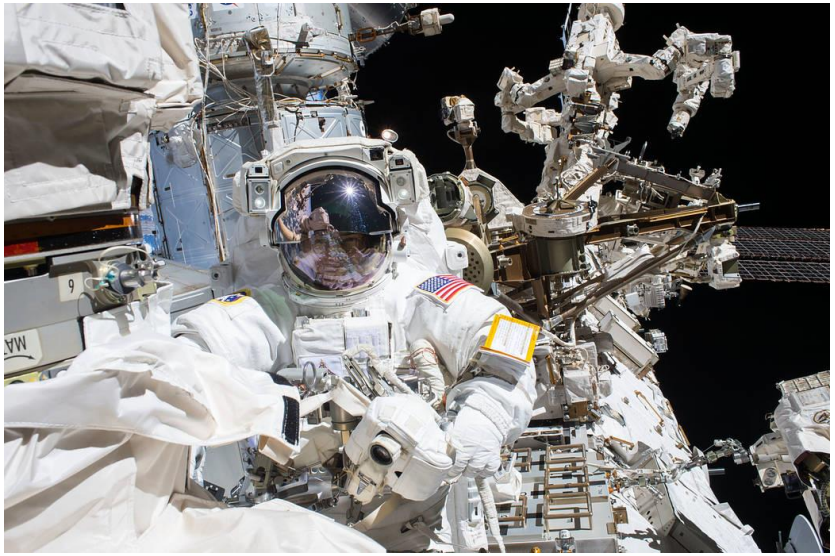


Source: Astronaut Mark Vande Hei verifies his U.S. spacesuit fits | NASA.gov

The ISS Program was fully prepped for USOS EVA to install the iROSA Mod Kit with assigned EVA Crew Vande Hei / Hoshide.

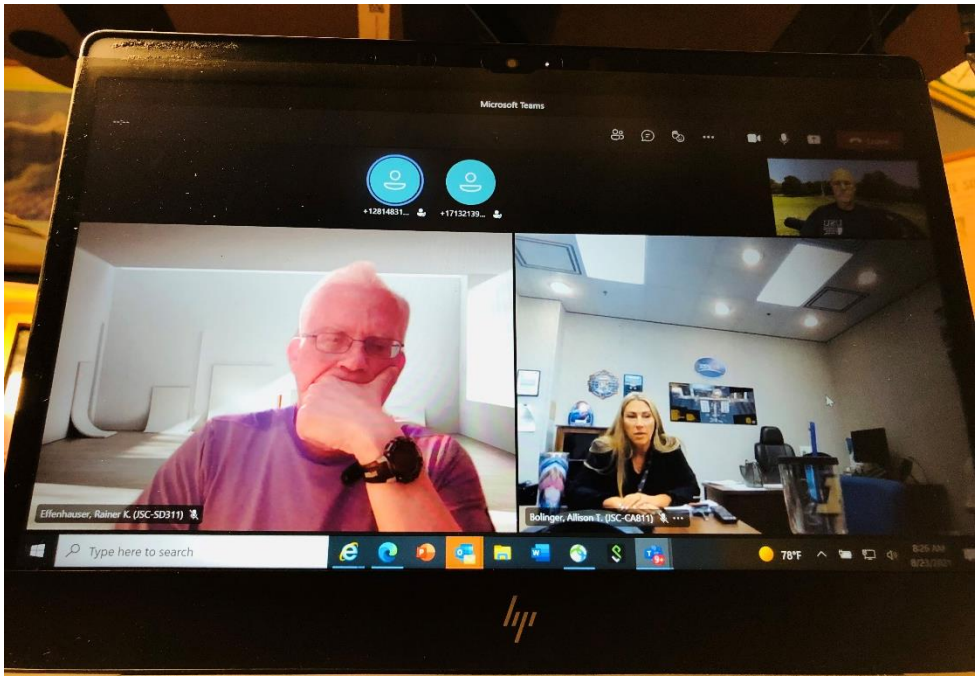
Failure->Impact->Workaround

- ISS Program Leads
- Increment Lead FD
- Astronaut Corps Chief
- Chief Medical Officer
  - HQ (Dr. Polk)
  - JSC (Dr. Taddeo)
- OPS PLAN
- Space Medicine Mgt
- Crew's family



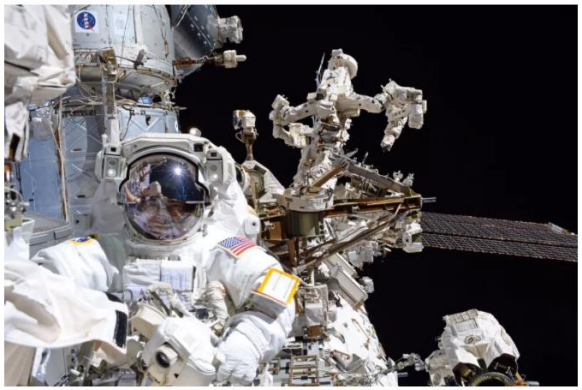
ISS053e079156 (Oct. 5, 2017) --- NASA astronaut and Expedition 53 Flight Engineer Mark Vande Hei is pictured during a spacewalk to service components on the Canadarm2 robotic arm during a spacewalk with NASA astronaut Randy Bresnik. Source: nasa.gov

Mission Impact Medical Event



Exp 64 crew surgeon meeting with ISS Increment Mangement Team, Flight Director, CMO

SPACE.com Subscribe



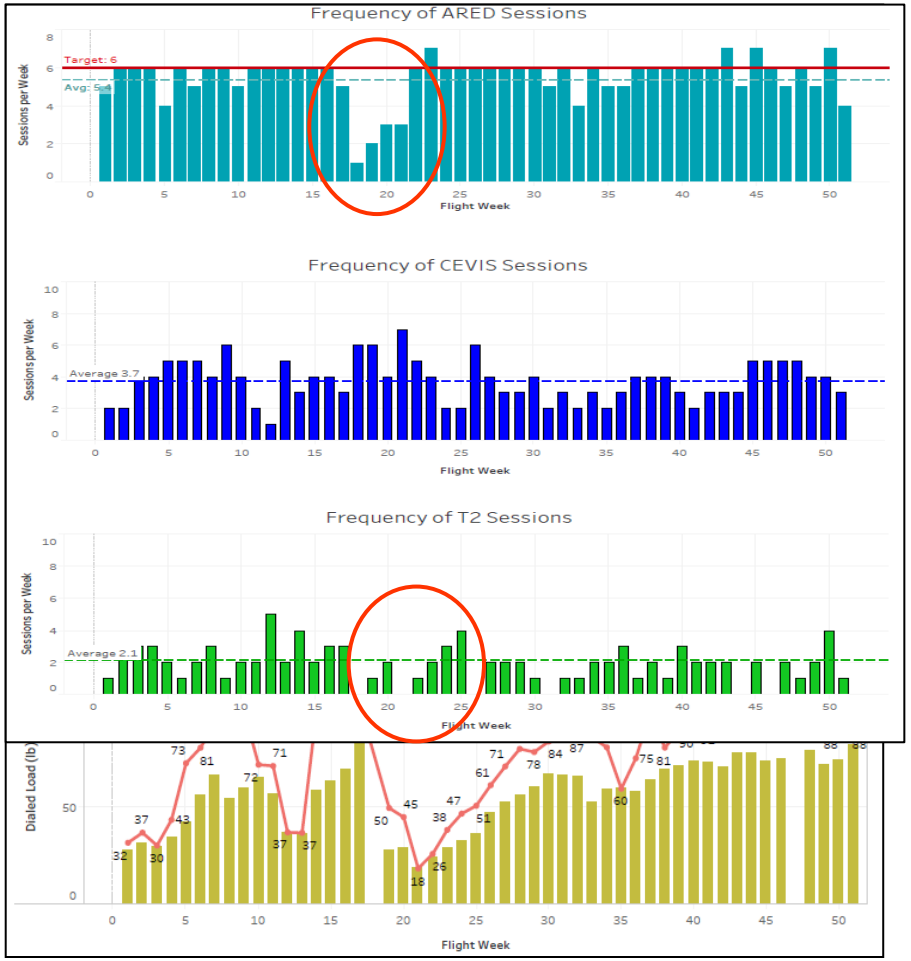
NASA astronaut Mark Vande Hei on a spacewalk outside the International Space Station in 2017. (Image credit: Randy Bresnik/NASA/Twitter)

NASA has called off plans for a spacewalk outside the International Space Station this week due a medical issue with one of the astronauts due to join the excursion, agency officials said Monday (Aug. 23).

Transition to On-Orbit Rehab…

Objective Exercise Impacts

- Trends in resistive (ARED) and T2 treadmill exercises before, during the acute injury and rehabilitation phase



Exercise alternatives

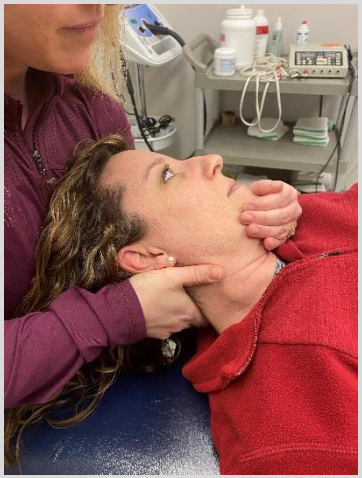
Daily, Impairment Based, Rehab Program

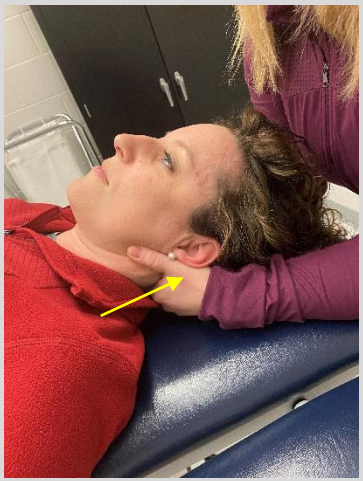
55 y/o male w/sharp scapular pain and numbness/tingling in to the 1-3rd digits

Young IA, Phys Ther, 2010

Biweekly, Impairment Based, Rehab Program

55 y/o male w/sharp scapular pain and numbness/tingling in to the 1-3rd digits





<u>Performed biweekly:</u> 15 second holds on/off repeated for 5 min for both, repeated 10-15 times or until resolution of symptoms completed this approximately 6 weeks

Young IA, Phys Ther, 2010

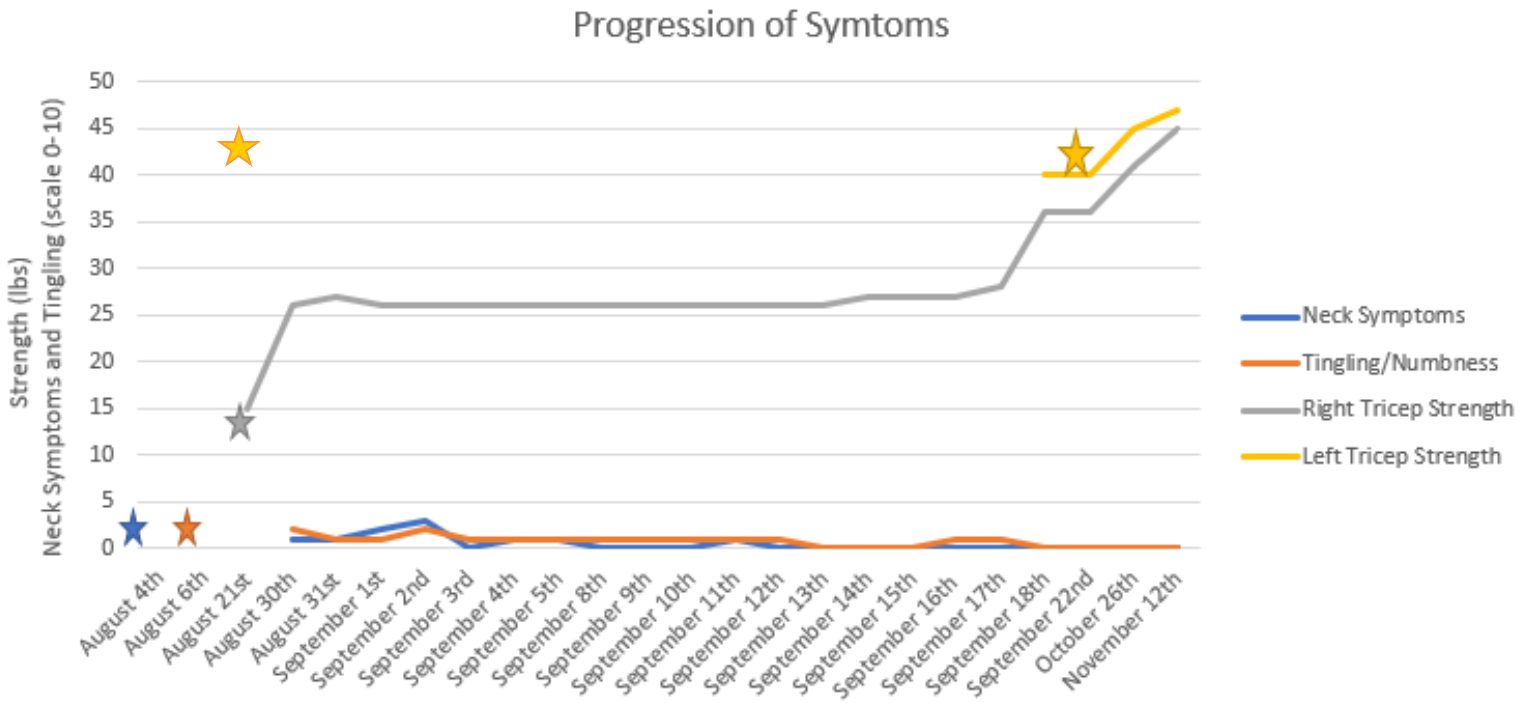
Biweekly, Impairment Based, Rehab Program

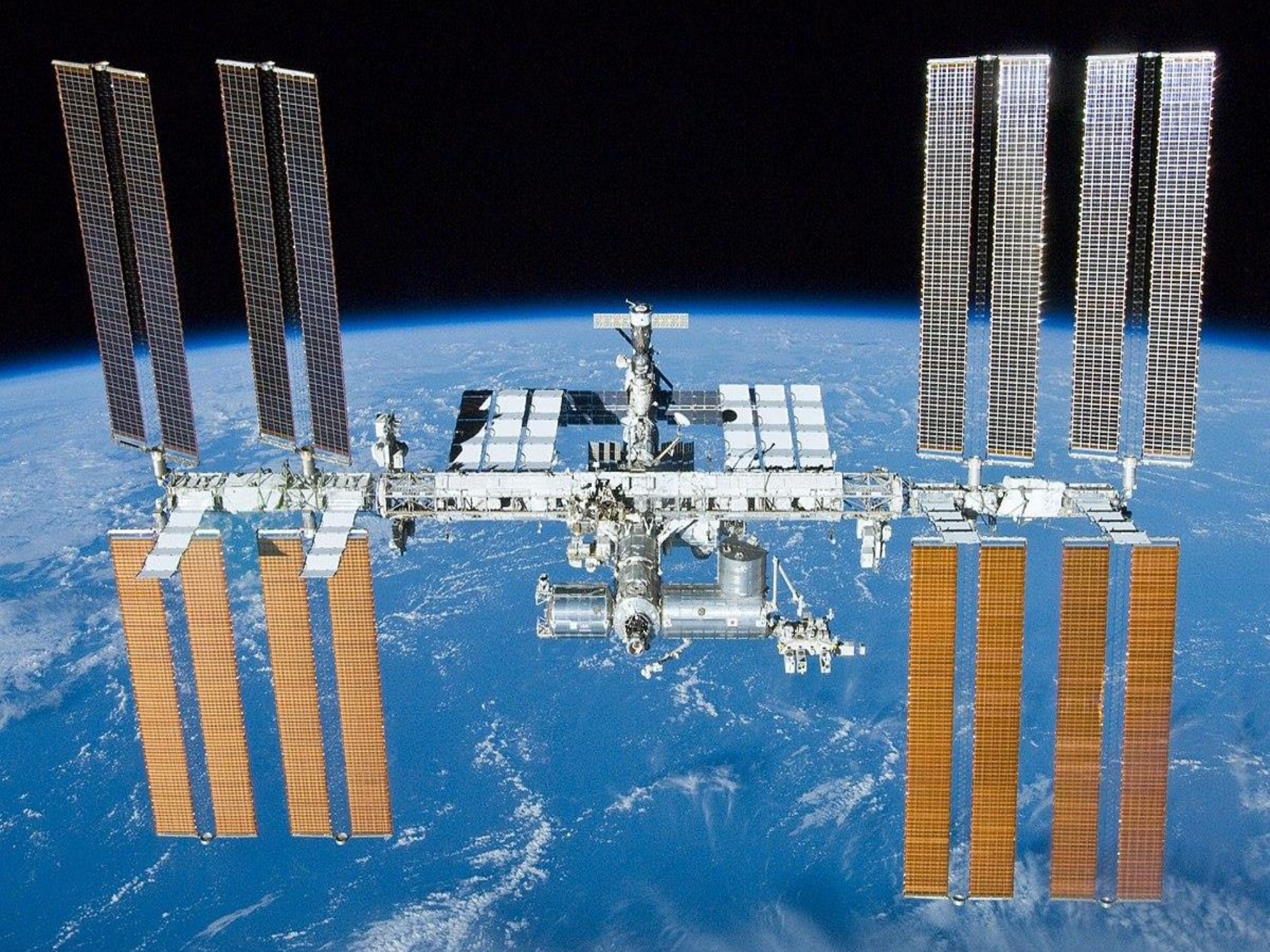
* Restraint was performed utilizing the Crew Medical Restraint System (CMRS)

* Astronaut physician made variations to place him at a mechanical advantage and resulted in a large upper extremity load to induce desirable forces to the cervical spine

Young IA, Phys Ther, 2010

Outcomes


Progression of Symtoms
Strength (lbs)
Neck Symptoms and Tingling (scale 0-10)
50
45
40
35
30
25
20
15
10
5
0
August 4th
August 6th
August 21st
August 30th
August 31st
September 1st
September 2nd
September 3rd
September 4th
September 5th
September 8th
September 9th
September 10th
September 11th
September 12th
September 13th
September 14th
September 15th
September 16th
September 17th
September 18th
September 22nd
October 26th
November 12th
Neck Symptoms
Tingling/Numbness
Right Tricep Strength
Left Tricep Strength



Case Progression

- Triceps weakness & Paresthesia resolved by ~October 2021
- Soyuz Landing 30 Mar 2022 (asymptomatic)
- Postflight Imaging (MRI x 2, CT) – see upcoming slides; Neurosurg Consult/Eval;
- Postflight rehab to Present (asymptomatic)

Landing Preparation

Soyuz seat and Sokul suit evaluation with Russian surgeon and trainer, building 9, NASA-JSC 10-March-2022.

Cologne, enroute to Karaganda

G5 crew enroute to Karaganda, Kazakhstan via Cologne, GE 25-Mar-2022.

65S Landing 30-Mar-2022

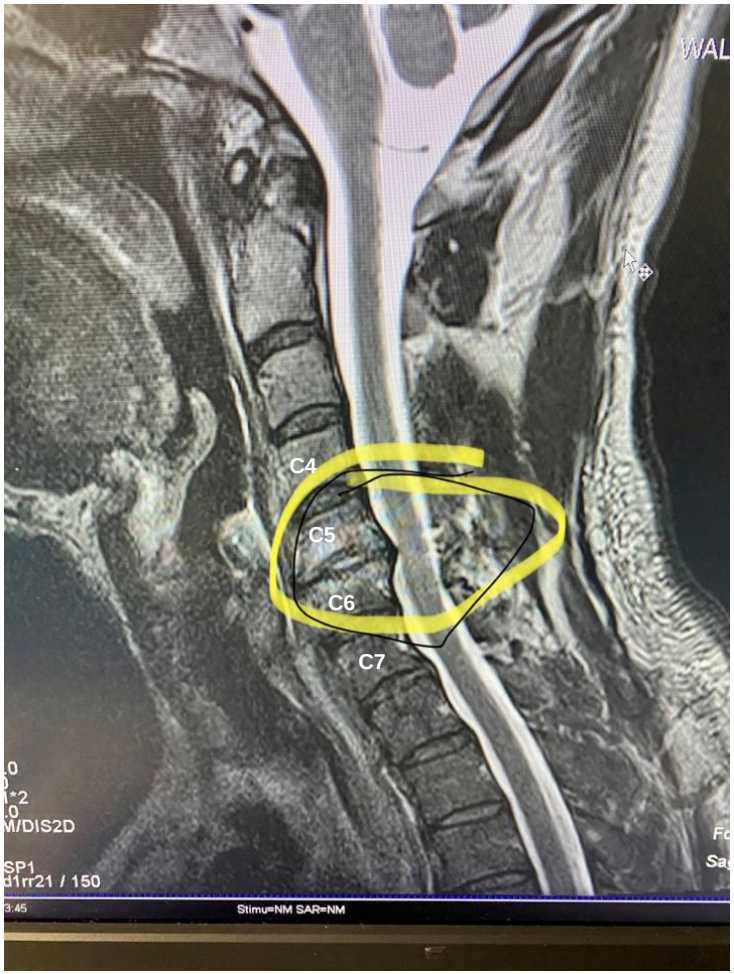
Landing 30 March 2022

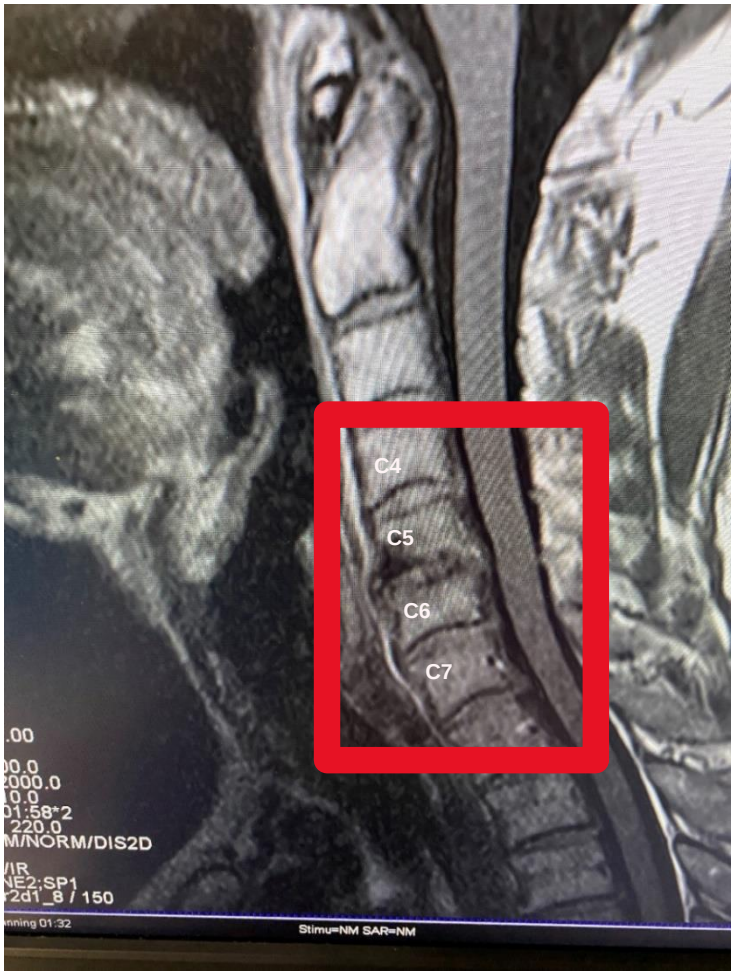
Dr. Rainer Effenhauser and astronaut Mark Vande Hei, 65S landing, steppes of Kazakhstan, 30-Mar-2022

30 March 2022

“Green Bay, Green Bay, Green Bay” reported from the 65S LZ, Kazakhstan 30-Mar-2022.

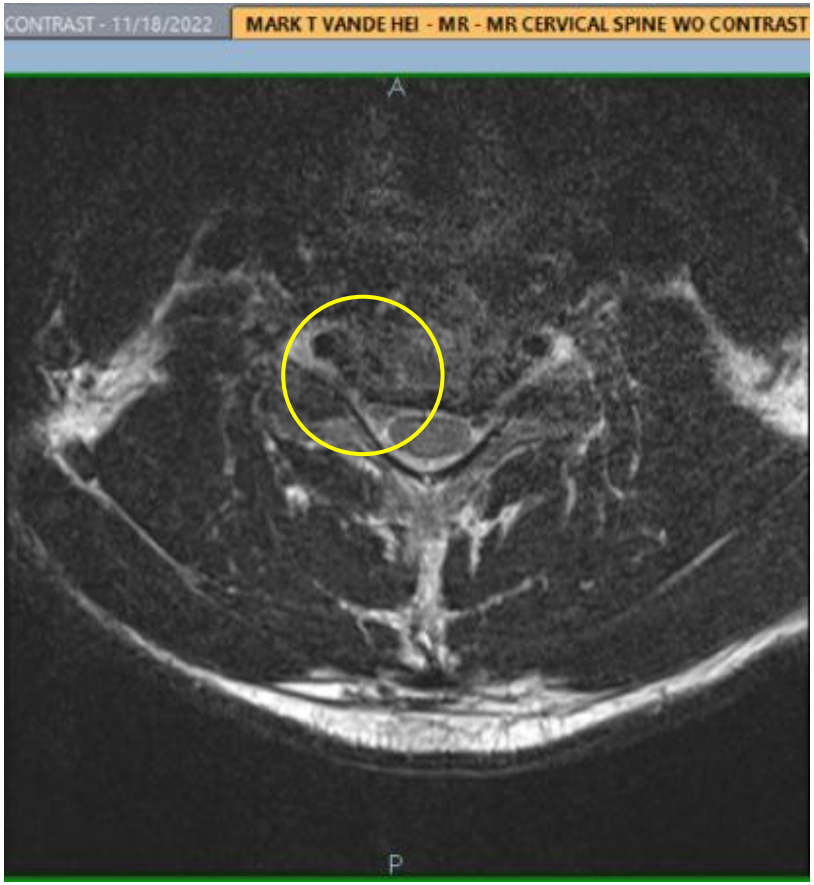
Cspine MRI 31-Mar-2022



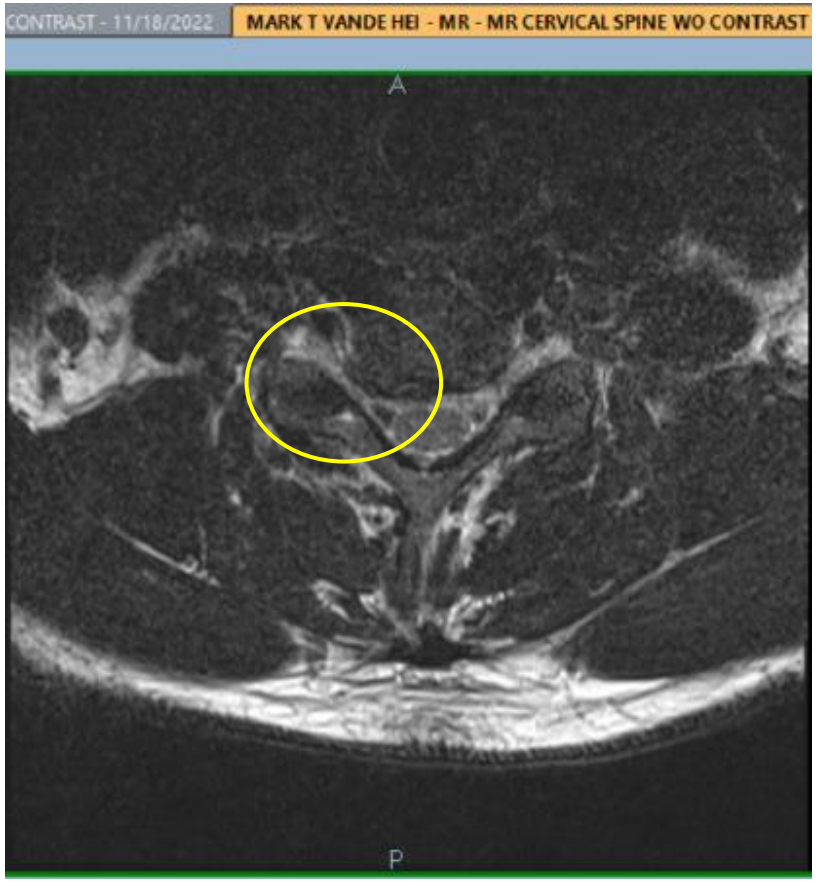


Cervical Spine MRI 30-Mar-2021

C5-C6

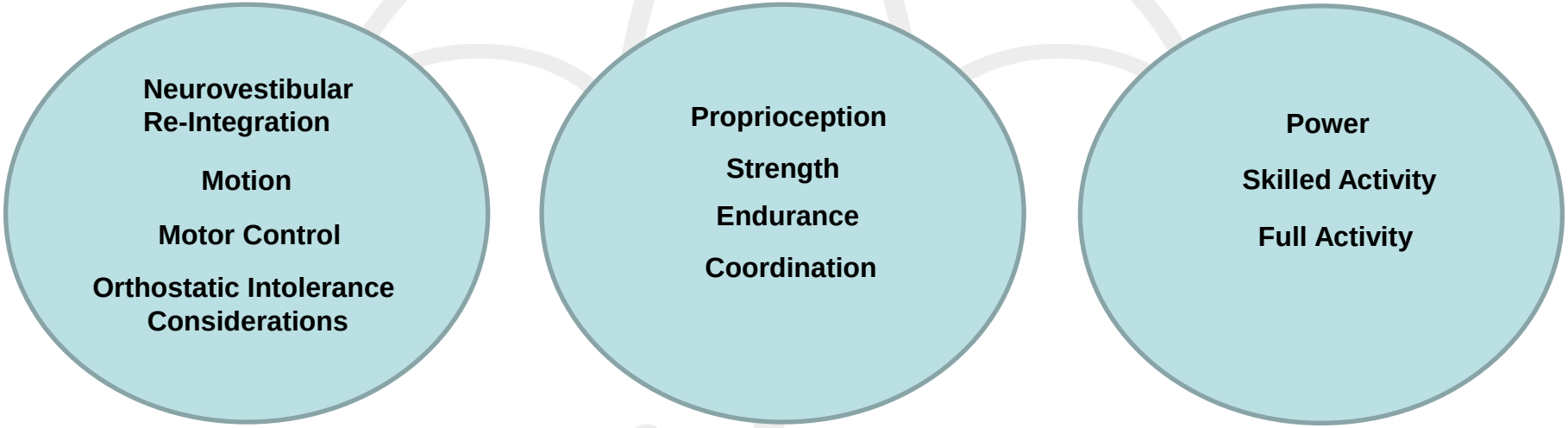


C6-C7



Post-Flight Reconditioning Considerations

Strength, Endurance, Coordination, Mobility, Speed



1.) Physiologic Effects of Space Flight

2.) Functional Abilities

3.) Crew Members Goals and Training Desires

4.) Other demands (operational, research, etc)

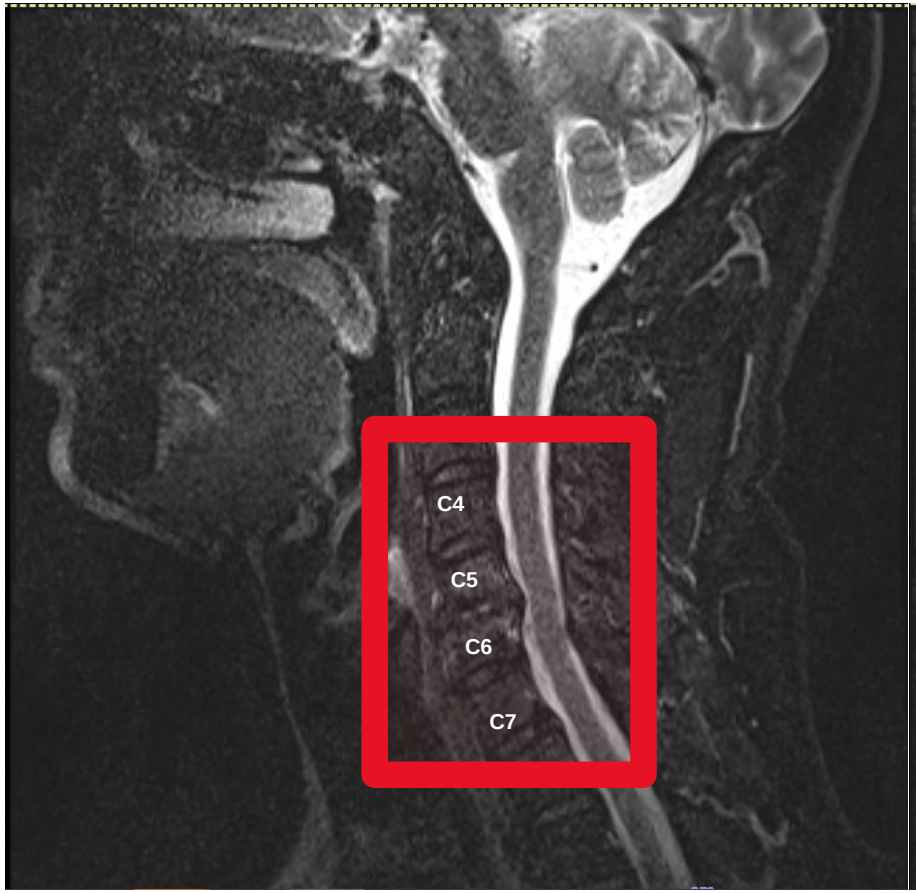
Post-Flight Considerations

- **Post Flight Cervical Related Impairments:**
  - Limited cervical range of motion (difficulty looking full over the right shoulder)
  - Complete resolution of numbness/tingling
  - Decreased cervical proprioception
  - Decreased deep neck flexor and extensor endurance (craniocervical flexion test-stage 1)

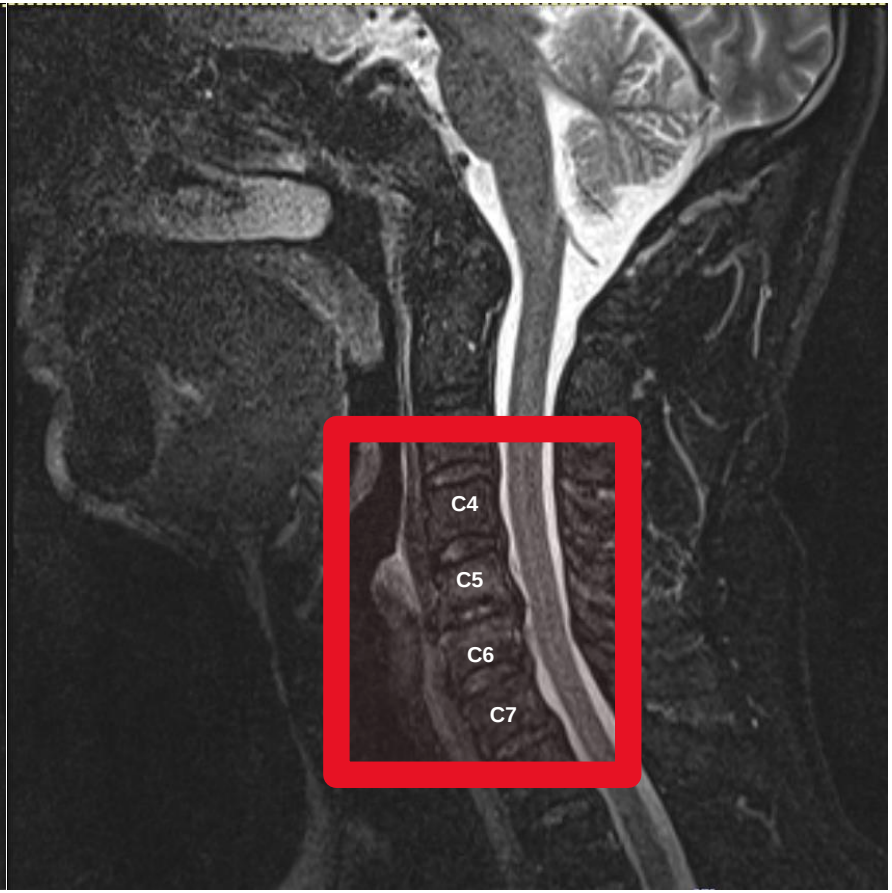
Rehab Summary

- Utilizing an evidenced based approach for diagnosis/treatment, combined with Crew Member ingenuity, lead to successful management of a complex cervical radiculopathy
- Consistent and frequent communication and monitoring of symptoms was vital to successful management
- A multimodal, conservative approach, can be accomplished on the Space Station to manage common MSK complaints and should be considered for future long-duration missions
- Symptoms were not provoked on return, however impairments lingered several weeks in to reconditioning
- At the completion of reconditioning, 45 days after return, there was full functional cervical mobility, improved DNF endurance with ability to complete full staged craniocervical flexion protocol, and no subjective complaints of pain or paresthesia

F/U Cervical Spine MRI

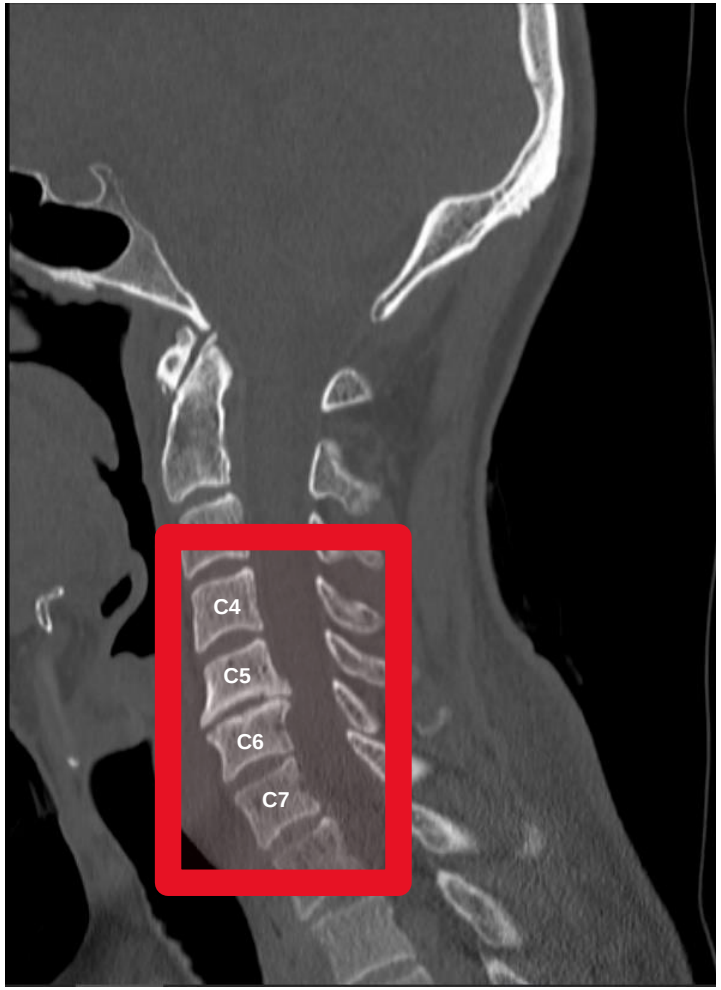


Sagittal MRI Cspine 18-Nov-2022



Sagittal MRI Cspine 29-Mar--2023

Cervical Spine CT 29 Mar 2023



Known Risks

- Increased Risk of Disk Herniation in Astronauts

Risk of Herniated Nucleus Pulposus Among U.S. Astronauts

Smith L. Johnston, Mark R. Campbell, Rick Scheuring, and Alan H. Feiveson

Aviation, Space, and Environmental Medicine • Vol. 81, No. 6 • June 2010

- Astronauts 4.3X more likely to have HNP
- Cervical Spine HNP was 41% of all HNPs

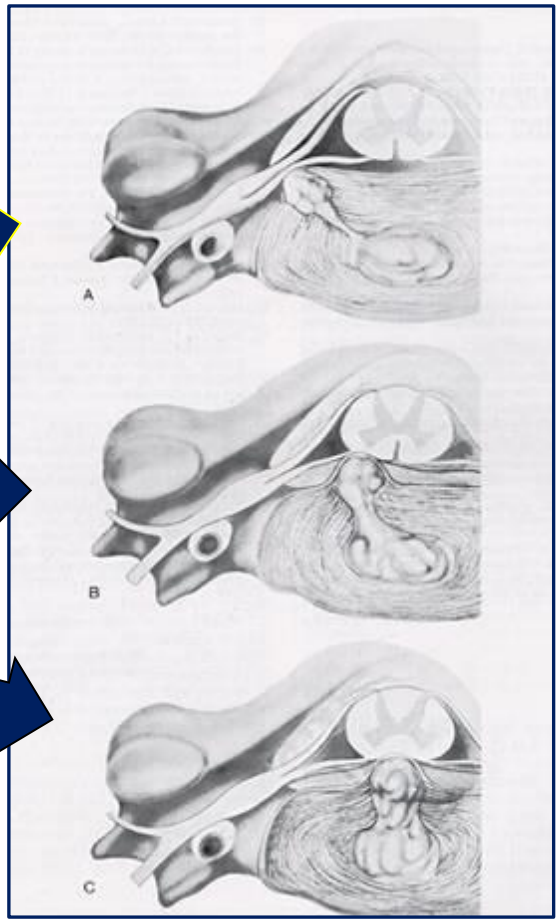
Unknowns

- What biochemical changes occur within the disk?
- What does traction do to the disk long term?
- Unknown Unknowns…

Cervical Disk Herniation

Cause majority of acute radiculopathies

- Intraforaminal: most common, radicular sx in dermatomal distribution
- Posterolateral: mostly motor symptoms (weakness and atrophy)
- Midline: may cause myelopathy and the next nerve root



Natural History

- 70-80% of radiculopathy resolves
  - First 3 months critical
- Concern for permanent weakness after 6 months
  - Monitoring remotely difficult
- Ideal surgical window between 3 and 6 months for weakness
  - Less if profound weakness or progression

Precedent

- Surgical Intervention
  - ACDF
  - Foraminotomy

JNS SPINE

HISTORICAL VIGNETTE

J Neurosurg Spine 31:87–92, 2019

Astronaut Michael Collins, Apollo 8, and the anterior cervical fusion that changed the history of human spaceflight

Richard Menger, MD, MPA,[1] Michael Wolf, MD, MS,[2,3] Jai Deep Thakur, MD,[1] Anil Nanda, MD, MPH,[1] and Anthony Martino, MD[4]

Disposition

- Recertify or Not for Long Duration Spaceflight?

Conclusion

- Cervical Spine architecture appears to be vulnerable to anatomic changes that occur in microgravity
  - Cervical versus Lumbar risk
- Expanded long duration flights
  - NASA – Mars
  - Outside organizations
- Flights longer than 3-6 months and symptoms don’t improve
  - Patient Risk/Mission Risk

Discussion: Risks & Mitigation

- Here's the aeromedical experts and consults case for *recommending recertification* for long-duration spaceflight:
  - Lessons Learned during 64S/65S – Proven ability for on-orbit diagnosis, medical treatment, rehab, exercise modification, inflight PT, eg cervical traction, manual therapy
  - Asymptomatic last 5 months of 1-year mission
  - Asymptomatic during/after 30-Mar-22 Soyuz Landing
  - Asymptomatic during postflight rehab to Present
  - Very Low likelihood of serious future symptoms (myelitis/cord compression) per consultants
  - Known distribution of affected cervical foramen / EVA?
  - On-orbit Meds/Imaging: Steroids, Ultrasound, Pain meds, Gabapentin?
  - If becomes symptomatic pre-flight, treatment could be single-level cervical fusion with high rate of success
  - Precedent Case(s): Several lumbar HNP and one known cervical HNP on ISS

Closing Comments

- In the future, All Astronauts now receive preflight Cervical and Lumbar MRI per new MedB Standard

Case Presentation- Summary

- A healthy 55-year-old with *known* cervical degenerative disk disease developed an acute left sided C7 cervical radiculopathy four months into his long duration space flight…
  - What factors would you consider in whether to allow him to return to space considering his orthopedic history?
    - He experienced symptoms in a state of permanent traction
    - He has known multilevel DDD, ie cervical neural foramen narrowing increases risk over unaffected individual
    - There is limited capability for emergent return
    - Limited on-orbit imaging capability vs. ground, limited on-orbit medical treatment capability
    - Confounding DCS symptoms w/neurological symptoms related to radiculopathy
    - Does radiculopathy recurrence risk increase or decrease with time?
    - Does he have increased risk for stenosis or myelopathy?