NEW HEIGHTS IN ULTRASOUND: FIRST REPORT OF SPINAL ULTRASOUND FROM THE INTERNATIONAL SPACE STATION

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Abstract—Background: Changes in the lumbar and sacral spine occur with exposure to microgravity in astronauts; monitoring these alterations without radiographic capabilities on the International Space Station (ISS) requires novel diagnostic solutions to be developed. Study Objectives: We evaluated the ability of point-of-care ultrasound, performed by nonexpert-operator astronauts, to provide accurate anatomic information about the spine in long-duration crewmembers in space. Methods: Astronauts received brief ultrasound instruction on the ground and performed in-flight cervical and lumbosacral ultrasound examinations using just-in-time training and remote expert tele-ultrasound guidance. Ultrasound examinations on the ISS used a portable ultrasound device with real-time communication/guidance with ground experts in Mission Control. Results: The crewmembers were able to obtain diagnostic-quality examinations of the cervical and lumbar spine that would provide essential information about acute or chronic changes to the spine. Conclusions: Spinal ultrasound provides essential anatomic information in the cervical and lumbosacral spine; this technique may be extensible to point-of-care situations in emergency departments or resource-challenged areas without direct access to additional radiologic capabilities. © 2014 Elsevier Inc.

Keywords—International Space Station; ultrasound; spine; telemedicine; remote care

INTRODUCTION

The International Space Station (ISS) medical support infrastructure has the capability to treat minor illness or injury for a crew of six members with a typical mission length of approximately 6 months. Although astronauts are screened for high-risk preexisting conditions, pathological processes may still evolve de novo during missions, and trauma is always a possibility. More common, however, are the variable and mostly transient changes associated with microgravity exposure. Among these, back pain in early days of flight and a pre- to postflight height gain of 2 inches or more is common. Spinal elongation is presumably due to an increase in intervertebral disk (IVD) volume and height, as well as straightening of the physiological curvatures of the spine. The changes to the vertebral column can conceivably increase the risk of trauma during resistive exercise and high-acceleration operations such as landing, especially if the seat configuration becomes suboptimal. Microgravity-induced changes of the spine have been described in literature based on pre- and postflight imaging and anthropometric measurements, but no in-flight spinal imaging has been attempted (1–7).

Ultrasound is increasingly relied upon for situations that benefit from instantaneous imaging results with an
immediate effect on clinical management. The processes of radiology services are not well positioned to meet these recently recognized needs, hence, many accurate and sensitive ultrasound techniques are performed by non-radiologist clinical providers serving on prehospital, emergency department, and intensive care teams. This trend has led to the proliferation of new ultrasound applications that have not been properly evaluated or accepted by the radiology discipline. Because the ISS imaging capability is limited to ultrasound, space medicine experts not only monitor developments in this area, but play leading roles in the discovery and promotion of new ultrasound techniques and approaches (8,9). Spine ultrasound is among the least developed areas of medical imaging, yet is attractive due to the broad availability and affordability of equipment, potential benefits for space physiology and medicine, and the sizeable terrestrial patient populations that do not have access to “gold-standard” diagnostic resources.

A modern multipurpose ultrasound system is manifest on the ISS, which is heavily used for research and medical surveillance purposes. A wide variety of complex ultrasound examinations are performed in space by astronaut operators who have had limited training. These examinations are supported by onboard training software and real-time remote guidance; the effectiveness of both clinical and research tele-ultrasound are now well established within the ISS program. This report, directly submitted electronically from the ISS, describes the first ISS-based imaging experience in a new area – spinal ultrasound, based on lumbar and cervical vertebral ultrasound sessions during ISS Expedition 34. Although developed and used as part of a spaceflight investigation, the techniques of spinal ultrasound are likely to become a valuable tool for health care providers on the ISS and in other resource-constrained environments for the evaluation of trauma and other acute and chronic conditions involving the spine.

MATERIALS AND METHODS

Subjects

The experimental protocol was performed in two healthy male volunteer astronauts, 52 and 53 years old, aboard the ISS, including ultrasound imaging of the lumbar and cervical segments of the vertebral column. The investigative procedures were approved by the Human Investigation Committee and the National Aeronautics and Space Administration (NASA) Lyndon B. Johnson Space Center (JSC) Institutional Review Board. The crewmembers received briefings and acknowledged their informed consent prior to the mission. Experimental data included full-resolution still images and cine-loops retrieved post-examination from the ISS ultrasound system, and a continuous low-fidelity video recording of the output of the ultrasound system.

Training, Equipment, and Communications

Astronauts attended a 1-h familiarization session up to a year prior to their mission that included a brief didactic presentation on the ultrasound (US) hardware and generic exposure to tele-ultrasound guidance. Approximately 3 months prior to launch, the crewmembers underwent a 1-h hands-on training at the Payload Development Laboratory (PDL) at the NASA JSC in Houston, Texas, to perform the experiment-specific procedures for spinal US. Crew training in the PDL involved focused imaging of the lumbar and cervical spine in a flight-like setting. The output of the US system from within the PDL was displayed on the remote sonographer’s workstation to enable flight-like remote guidance for subject positioning, probe placement and manipulation, and equipment adjustments. Additionally, the astronauts were introduced to the 30-min multimedia refresher course – an experiment-specific computer-based program to be used within 24 h prior to the US session on the ISS (Figure 1).

Both training and in-flight US examinations were performed using identical GE Vivid q ultrasound systems (GE Medical, Milwaukee, WI). The 4C-RS and 8C-RS broadband curved array probes were selected for the lumbar and cervical regions, respectively. The images were viewed by the operator on the US system screen and were transmitted simultaneously to remote US guidance experts via local circuits (in training sessions) or satellite broadband transmission (ISS-based sessions). Due to distance, data relaying, and conversions, the latter included a delay in transmission to the Telescience Center at

![Figure 1. A sample screen from the experiment-specific multimedia training software that is reviewed by the operator within 24 h of the imaging session.](image-url)
JSC, where the ground-based sonographer viewed the video output from the US machine with near real-time (1.6-s delay) conditions. The video transmission and the two-way voice connection with the US operator were configured as “private” channels for privacy purposes. Each session was scheduled for 1 h.

The US imaging of the lumbar and cervical spine was conducted early in the crew workday in a semi-fasting state (no heavy meals) and prior to any physical exercise. To maintain the spine in a neutral and reproducible position for the examination, the subject was placed on the Crew Medical Restraint System (CMRS) – a flat, sturdy support structure. To maintain stability in microgravity while force is applied to the transducer, the astronauts were asked to use physical restraining techniques for both the subject and the operator. Other positioning was ergonomically designed to minimize operator hand fatigue and allow for glare-free direct view of the screen with easy access to the US system’s keyboard and the anatomical areas of interest.

Imaging Technique – Lumbar Spine

Lumbar US imaging was performed using standard US gel as an acoustic medium and a 4C-RS convex array probe with a central frequency of 4.0 MHz. The initial probe placement and subsequent adjustments of probe pressure force and fine probe manipulations were directed by the ground-based investigators using standardized terminology. Preflight (baseline) magnetic resonance imaging (MRI) and US images were available to verify the consistency of the views and their adequacy for future analysis.

The initial target, the L5–S1 IVD space was identified longitudinally from a mid-sagittal approach with the reference marker toward the subject’s head. This landmark has a recognizable contour with the sacrum curving posteroinferiorly from the point of sacral promontory, and the IVD space directed posterosuperiorly (Figure 3). The optimized mid-sagittal image of lower lumbar spine (Figure 3) allows the identification of the anterior longitudinal ligament and the sharp hyper-echoic contour of the cortical bone of the vertebral bodies and the promontory, with clearly visible and slightly elevated anterior edges of the disks.

To obtain the transverse view of the L5–S1 disk, the probe was translated inferiorly to a position directly anterior to the disk and then panned, while still remaining in the same plane, to orient the disk space vertically on the screen. In guidance terms, the cable end of the probe was inclined in the direction of the subject’s feet by 25–30°. The probe was then rotated 90° counterclockwise, placing the reference marker to the subject’s right. After fine adjustment of the imaging plane to coincide with the plane of the IVD, the US beams had a direct path through the disk, resolving the structure of the disk itself, including its annulus fibrosus and the relatively hypoechoic nucleus pulposus. This view also featured the posterior longitudinal ligament and the cross-section of the thecal sac with its contents. At the lower lumbar levels, normal features of the thecal sac are clear – its symmetry and visible nerve roots, especially the most prominent S1.

The protocol repeated the above steps for L4–5, L3–4 (Figure 4), and L2–3 IVDs, first obtaining mid-sagittal views and then rotating 90° over each targeted IVD to obtain images in the plane of the IVD. The abdominal aorta was used as an acoustical window for L2–3 and L3–4 IVDs, but not for L4–5 IVD because the bifurcation was at the level of the L4 body in both subjects. In longitudinal views, care was taken to direct the scanning plane to the middle of the anterior surface of the bodies to correctly reflect the mutual positions of the vertebrae along the lumbar curvature.

The transverse colon presented a predictable obstacle for the transverse view of L2–3 disk space because the free edge of the colon was found at that location. In one of the subjects, gentle graded compression by the probe allowed manual shifting of the transverse colon cranially sufficient to obtain a satisfactory transverse view at this level. Moving cranially past the transverse colon, it was possible to examine the upper lumbar and lower thoracic regions to characterize the mutual position of these vertebral units. However, probe compression range at these
levels was limited, and the imaging quality for deep structures was degraded due to the greater distance to target structures and attenuation by a multitude of echogenic abdominal and retroperitoneal structures. Because the lower lumbar region is responsible for the vast majority of IVD pathology, we assign lower priority (and less in-flight scanning time) to achieving good visualization of the spine at the upper lumbar and lower thoracic levels.

Figure 3. Midline sagittal images of the lower lumbar segment. Top: (A) Initial longitudinal view, not optimized. (A') The same image with identification of the L4, L5, and S1 bodies (yellow outline) and intervertebral disks (IVDs) (blue highlight). The solid white lines show probe orientation for the transverse view. Bottom: (B) An optimized view of L4 and L5 bodies, the L4–5 IVD, and a segment of the spinal canal at the bottom of the image. (B') The same image with red highlights of the aorta and left common iliac artery used as acoustical windows. The spinal canal is highlighted in orange. White arrow = posterior longitudinal ligament; black arrow = edge of the vertebral end plate of L5. Note that the white solid line through the L4–5 IVD is vertical and in the middle of the image; the probe may now be rotated to obtain the transverse view of the IVD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Figure 4. (A) The initial transverse view of the spinal column through the cervical C5–6 intervertebral disk (IVD). (B) The transverse view of the lumbar L3–4 IVD. The reflection of the anterior longitudinal ligament (ALL) is identified with the white arrow. Note the clear demarcation of the posterior margin of the disk without bulging or herniation and reflection of the posterior longitudinal ligament (yellow arrow). Central areas of the disk (nucleus pulposus) have lower echogenicity (darker) than the periphery (annulus fibrosus). Note the lack of strong echoes within the disk. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
**Imaging Technique - Cervical Spine**

Imaging of the cervical spine was performed with a small-footprint 8C-RS micro-convex probe with a central frequency of 8 MHz. Potable water was used as the preferred acoustic coupler to minimize or eliminate probe pressure on the supple neck structures. The subjects remained on the CMRS restraint system to maintain the cervical spine in a standardized position. Similarly to the lumbar imaging techniques, the astronaut operator is guided through probe placement and subsequent fine adjustments necessary to obtain optimized images, with longitudinal views to be used mostly for cervical curvature and mutual positioning assessment and transverse views – to characterize the structure and relationships of the IVDs. A view from the true mid-sagittal approach in the neck is blocked by the airway, and pressure is not well tolerated. Longitudinal views of the cervical spine are acquired in oblique sagittal planes, bypassing the airway on either side, optimized by manipulating the imaging plane to reach the anterior surface of the vertebrae at mid-sagittal plane, at least significantly medial to uncinate processes. The left side is preferred due to the (frequently) leftward-deviated esophagus, which is a better acoustical window than the echogenic loose connective tissue.

The initial probe placement is at the C7–T1 IVD level, as this landmark is directly superior to the clavicle, exhibiting a characteristic posterior curve into the thorax. The next level is the C5–C6 IVD space imaged longitudinally from the left or right for the best approach, depending on image quality and anatomic constraints; the thyroid gland is a useful acoustic window. Placement of the probe too far laterally (e.g., using the lateral part of the thyroid lobe, common carotid artery, and the internal jugular vein as acoustic windows) prevents acceptable views of the mid-sagittal contour of the cervical column due to an acute angle of the incident beams relative to the anterior surface of the vertebral bodies, while the contour of the bodies in the lateral aspect does not contain information about the cervical curvature.

The optimized mid-sagittal view of the cervical spine must show the distinctly hyperechoic contour of the bodies with the overlying anterior longitudinal ligament, which has mild outward waves corresponding to each IVD. For the purpose of monitoring the spine curvature over time and across mission phases, consistent probe position is important; close proximity to the trachea on the left side seems to be the most reproducible approach to obtain these views.

At all cervical levels, similar to the lumbar region, views co-planar with the IVD were sought, even if longitudinal (oblique sagittal) views were not attainable due to the wider larynx and smaller vertebral bodies in the upper cervical region. Rotation by 90° from the longitudinal plane and alignment to the plane of IVD allowed resolution of the structure of the IVD and provided a good view of the posterior border of the *annulus fibrosus*, which was assumed to be the PLL. During this alignment, care was taken to avoid confusing the PLL line with a more shallow line caused by a partial beam reflection from the interface of the vertebral end plate with the annular epiphysis-derived compact bone (shown in a sample transverse lumbar and cervical IVD images, Figure 4). Gentle tilting of the probe helped recognize and eliminate this signal, and stabilized the view with a disk border that corresponds to the PLL depth.

Unlike the lumbar spine, US images from the cervical spinal canal reveal the spinal cord. In real-time imaging the spinal cord is weakly echogenic, rhythmically oscillating with an echogenic ventral median fissure and central canal; the anatomical and dynamic information available from this view is considered by the experiment team for analysis and use in future clinical and research protocols. A special technique was developed for obtaining a transverse view of the spinal canal through the atlantooccipital ligament – at the level closest to the intracranial space. This view was easier to achieve through the space above the laminae of the atlas, with the probe placed immediately medial to the apex of the mastoid process. Figure 6 is an optimized image of the cord shape and connective and vascular structures.

**RESULTS**

**General Procedures**

No hand fatigue or other discomfort was reported by the operators in contrast with some prior reports, possibly due to enhanced attention to the ergonomic layout of the experiment. The astronaut operators used a combination of foot restraints and wedging under the crew medical restraint system to maintain both stable positioning and reasonable freedom of movement in the microgravity environment (Figure 2). This active positioning allowed the operator ready access to the subject and the US machine while having stability against counterforces when pressure is exerted on the US transducer.

The discourse of remote guidance was adequate and the vast majority of directions were perceived and followed as intended. Both crewmembers served in both roles (operator and subject) and were satisfied with the quality of communication and the tempo of the procedure. Cabin video was downlinked in real time to provide additional insight into the scene of the examination, and the probe position was occasionally verified or corrected with the help of this additional visual source.
Data – Preliminary Results

US images of the cervical and lumbosacral spine regions were compared to preflight MRI data to identify anatomic similarities and concurrence.

Comprehensive lumbar and cervical spine US examinations were completed in approximately 60 min by the nonexpert astronaut operators. The downlinked US video stream provided very good-quality images of the examined spinal areas that could be used to exclude significant spinal abnormalities or injury at the level of examined segments.

The operators easily obtained high-quality images of the anterior and cervical vertebra through vascular windows and were able to localize the intervertebral disk spaces from L5–S1 to L1–L2 and C7–Th1 to C2–C3. There was no appreciable difference in image quality between preflight US images acquired by an expert sonographer on the ground during baseline data acquisition and the images obtained by the crew during in-flight operations. Using water as an acoustic medium was successful with muscle anatomy imaging requiring light probe pressure; however, standard acoustic US gel was a more suitable medium for imaging the spine, IVD, and surrounding spinal tissues.

US imaging of the lumbar vertebrae was readily performed through a left paramedian position using the aorta or inferior vena cava as an acoustic window. The L5–S1 disk space was easily recognizable by its characteristic contour (Figure 3) and provided a reproducible landmark to identify the other vertebral elements. Excellent visualization of the intervertebral bodies and disks of L4, L3, and L2 were obtained with this technique. The superior and inferior lips of the lumbar vertebra have a partially

Figure 5. Midline sagittal (top) and transverse (bottom) images of the lower cervical segment. (A) Initial longitudinal view through the right thyroid lobe, not optimized. (A) The same image with identification of the C5 and 6 vertebral bodies (yellow highlight), C5–6 intervertebral disk (IVD) (blue highlight), strap muscles (S), thyroid gland (Th), the longus colli muscle (red highlight), and the spinal canal (orange highlight). (B) Optimized view of C5–6 IVD, the spinal canal, major vessels and soft tissues of the anterior neck. (B) The same with highlights of the IVD (V), the spinal canal (orange highlight), common carotid artery (C), longus colli muscle (L.c.), and the trachea (T). Additional probe manipulation is necessary to emphasize specific structures for consistent assessment and comparisons with prior data.
squared symmetry that facilitates measurement (Figure 3). Transverse imaging of the intervertebral disk and spinal cord was completed at multiple levels (Figure 4). The image quality allowed assessment of the IVD size and would allow visualization of significant retropulsion abnormalities.

The margins of the cervical vertebrae have a rounded geometry that complicates measurement of the IVD in the cervical region (Figure 4). Sagittal imaging of an IVD provides excellent visualization of a localized section of the spinal cord and surrounding tissues (Figures 5, 6).

The anatomic features of the in-flight US images compared favorably to the preflight MRI data sets. Subtle anatomic variants in the subjects were identified on the in-flight US scans in all regions. This concurrence of imaging techniques suggests that many clinically relevant abnormalities of the cervical or lumbosacral spine can be identified using this technique.

**DISCUSSION**

The ability to provide medical care aboard a spacecraft is challenging due to the limited availability of specialized medical expertise and medical equipment onboard; in this sense the ISS is similar to a limited-resource medical setting on Earth (10–14). The crews of the ISS receive training in a wide variety of tasks, including emergency medical procedures. A crew medical officer (CMO), who is generally not a physician, receives a total of approximately 40 h of additional training in medical diagnosis and therapeutics. A physician crewmember, although offering a tremendous advantage over nonmedical CMOs, may not be specialized and current in all medical disciplines, and will still defer decisions to specialist colleagues in many cases. Telemedicine systems are diverse in their scope, organization, and technical solutions, and attempt to meet the need for the specialized expertise required to diagnose, triage, or treat remote patients while ensuring the best possible outcome.

The current experiment uses telemedicine solutions available within the ISS Program to develop and validate new noninvasive techniques for the assessment of the spine. MRI is considered the “gold standard” modality for spine visualization, although the majority of the world’s population does not have access to MRI. Ultrasound, however, is an affordable and portable modality that is rapidly becoming ubiquitous, with an ever-growing toolbox of accurate and repeatable applications. Point-of-care US is also used in many trauma centers and advanced facilities to guide treatment when rapid diagnostic determinations immediately influence patient management and improve outcomes (15–18). Tele-ultrasound has been shown as another pathway for the generation of vital real-time information when the equipment is operated by nonradiologists or even nonphysicians (19–22). The authors of this article have demonstrated, validated, and successfully promoted a number of point-of-care US and tele-ultrasound solutions for prehospital, emergency, critical care, and remote medicine settings (18,20,23–25). In-flight back pain and an increased rate of postflight spinal injuries in crewmembers has inspired this particular study, and has driven the need for in-flight imaging of the spine for the purpose of characterizing microgravity-induced changes to the spinal unit.

There has been a consistent observation of increased height in shuttle astronauts and long-duration crewmembers during exposure to microgravity (2,22,26,27).
Height measurements conducted on orbit have consistently shown an up-to 3% increase; however, the exact mechanism is unclear. Proposed causes include alteration and redistribution of postural muscle tone, gravitational unloading of the intervertebral disks, and an increase in disk water content/composition. Back pain is a frequent medical complaint in astronauts during early adaption to microgravity conditions; fortunately, this has not resulted in an appreciable challenge to mission requirements or objectives. Quantification and characterization of spinal changes has relevance to the well-being of the crewmembers in flight and post flight, but there are unique safety concerns during the Soyuz spacecraft landing if spinal elongation has resulted in an overly tight fit in the personal Kazbek seat liner, which may place the crewmember at increased risk of injury during mechanical stress (6,28).

The musculature of the paraspinal and trunk area provides structural stability to the spinal unit. Muscular deconditioning is commonly associated with exposure to microgravity or prolonged bed rest; reduced biomechanical forces from space-induced atrophy of lower back muscles and correspondingly increased forces on the facet joint capsule may lead to back pain and increased chances of injury in crewmembers.

Remote US guidance by an experienced sonographer virtually brings imaging expertise to the point of care where a modestly trained US operator can perform the examination. The operator places the probe in a predetermined and familiar starting point (aided by topologic reference cue cards or other visual aids), and the video stream from the US device is displayed both on the on-site monitor and transmitted to a remote location, where it is viewed by the experienced sonographer. Optimal probe position and device settings are guided with voice commands from the remote sonographer to obtain the necessary images. The remote guidance paradigm substantially reduces initial and refresher operator-training requirements and allows experienced sonographer input during the conduct of the examination. We have combined remote guidance with a focused review of complex US to complete vertebral musculoskeletal examinations. Novel “just-in-time” computer-based training allowed preflight and in-flight training time to be reduced substantially.

This report demonstrates for the first time that high-quality US images of the lumbosacral and cervical spine may be acquired by nonexpert operators using remote guidance techniques, and requiring only a brief training session. These spinal US images provided precise details of many anatomic features of the spine and may help clinical decision-making for patients with spinal complaints or injury. This new spinal US technique may have several advantages over current imaging technologies, including portability, ease of performance, repeatability, and the lack of ionizing radiation.

The ability of the ISS crew to perform complex US examinations aboard the ISS supports the hypothesis that minimally trained US operators can perform high-fidelity, diagnostic-quality examinations when directed by a remote-based experienced sonographer. The images acquired by the astronauts in this study were of excellent content and quality, and in a medical contingency scenario, they would have provided essential information to guide clinical decision-making. There were no discernible differences between the US examinations performed on orbit and those performed in standard terrestrial conditions when the images were evaluated by an experienced sonographer.

The optimal training of crewmembers for the ISS and later exploration-class missions is still being defined. This initial US experience with a novel examination suggests that limited training, combined with computer-based refresher information and directed remote guidance, may be an effective technique for performing complex tasks. The examination was conducted within a strictly limited time frame, which would likely be the case in most terrestrial situations, such as military settings and remote medicine with limited communication capability.

Limitations

This study is limited by the small number of subjects inherent in performing human investigations on the ISS. Mission timeline constraints, and the complex nature of performing scientific experiments requiring coordinated activities of multiple crewmembers preclude large number trials in space. Astronauts undergo rigorous selection examinations to qualify for spaceflight, therefore, a subject bias is introduced that excludes significant spinal pathology. The ability of the current study to determine the diagnostic accuracy of spinal US in the detection of pathology could not be verified due to the study constraints.

CONCLUSIONS

The unique constraints imposed by the space environment require the development of detailed training, diagnostic, and therapeutic strategies. Although many of the procedures investigated by NASA are appropriate only for the space environment, many spaceflight-derived techniques are readily transferable to the Earth, including rural, military, and emergency medical care scenarios. Using US images to classify disk conditions remains in development; there is no consensus on grading US image characteristics (normal to pathology) or qualifying IVD injury. In austere environments without access to MRI
and CT (the mainstream standard in terrestrial care), US may prove a reasonable choice for a focused examination. This brief report documents a reproducible standardized US technique to visualize the cervical and lumbar vertebrae to evaluate the IVD and evaluate spine-related complaints or injury. The technique produces consistent results that compare favorably with MRI standards. The remotely guided US concept, with crew medical officers or comparably trained first responders as operators, is an important and clinically relevant advancement in space medicine; the addition of spinal US provides an additional tool with profound ramifications for emergency or clinical medicine.

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ARTICLE SUMMARY

1. Why is this topic important?
   This study is the first description of point-of-care ultrasound evaluation of the lumbar and cervical spinal anatomy. Portable ultrasound devices have expanded medical care capabilities; this new technique may expand diagnostic capabilities.

2. What does the study attempt to show?
   This study describes a new technique of just-in-time training, combined with remote expert guidance, to obtain high-quality spinal images to evaluate acute changes to spinal anatomy caused by chronic exposure to reduced gravity.

3. What are the key findings?
   Nonexperts can obtain high-quality images of the lumbar and cervical spinal anatomy that correlate with magnetic resonance imaging (MRI) images.

4. How is patient care impacted?
   There is no radiographic capability on the International Space Station. This ultrasound technique provides a rapid assessment of the cervical and lumbosacral spinal anatomy to assess acute changes in crewmembers in space. The described technique would provide similar capabilities on Earth, after verification studies, in under-served or remote environments, or in situations where computed tomography or MRI is not available.