BENEFITS OF HUMAN SPACEFLIGHT: INTERNATIONAL SPACE STATION (ISS) AND BEYOND

Testimony Before the
Subcommittee on Science and Space
Committee on Commerce, Science and Transportation
United States Senate

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April 20, 2005

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Madam Chairman, Ranking Member and Distinguished Members of the Subcommittee:

Thank you for the opportunity to present testimony on the benefits of human spaceflight as it relates to the International Space Station (ISS) and beyond. As Director of the National Space Biomedical Research Institute (NSBRI), my statement addresses each of the topics outlined for this hearing. These are (1) benefits of human spaceflight in the context of ISS development and current ISS operations, (2) future opportunities using the ISS for operations, engineering, commercial and scientific research and applications that support exploration and other national missions, and (3) possible management transition opportunities that increase private sector involvement in the ISS. The issues are complex, but important, as NASA moves forward under the leadership of its new Administrator, Dr. Michael Griffin.

Benefits of Human Spaceflight in the Context of ISS Development and Current ISS Operations

The ISS is the most sophisticated engineering structure ever constructed in the history of humankind. It provides a unique, precious resource for the U.S. and its international partners to develop innovative technologies, knowledge and infrastructures to support U.S. space exploration goals. The ISS has now been continuously crewed for more than four years, and it is an invaluable test bed for exploration.

The NASA Administrator has outlined the need for an exciting, outward-focused, destination-oriented space program, which includes both human and robotic exploration and aeronautics. Dr. Griffin has also affirmed that the completion of the ISS, in a manner consistent with commitments of international partners and the needs of human exploration, is a priority. This view is consistent with the President's Vision for Space Exploration, articulated on January 14, 2004. One of the three main activities listed for the ISS in low-earth orbit is to focus U.S. research and use of the ISS on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities, and developing countermeasures.[1]

[1] The other two activities listed for the ISS in low-earth orbit are (1) complete assembly of the ISS, including the U.S. components that support U.S. space exploration goals and those provided by foreign partners, planned for the end of this decade and (2) conduct ISS activities in a manner consistent with U.S. obligations contained in the agreements between the U.S. and other partners in the ISS.

While the extent of scientific research and development being performed on ISS is limited in the wake of events following the tragic loss of Columbia and her valiant crew, important progress and discovery are nevertheless taking place. Experience is being gained on the reliability of critical hardware systems, including life support. There is increased emphasis on autonomy and performing maintenance inflight rather than replacing parts from the ground.

Innovation continues to have a strong presence, as illustrated by the recently published, first scientific report ever submitted from space, involving the testing and evaluation of ultrasound as an exploration medical capability.[2] The study was made possible by the unique, long-duration exposure to microgravity afforded crew members aboard the ISS.

Future Opportunities using the ISS for Operations, Engineering, Commercial and Scientific Research and Applications that Support Exploration and Other National Missions

With a shift in emphasis of the human space program from low-earth orbit to destinations beyond, new priorities and exciting mission possibilities arise. It is imperative in developing a balanced, overall program of science, exploration and aeronautics to capitalize on the unique test platform of, and nation's investment in, the ISS.

The strategic planning process for ISS should integrate with plans for other systems, such as transportation, wherein the Shuttle retires and the Crew Exploration Vehicle (CEV) seamlessly comes into service. Strategic goals should also take into account continuity of scientific and technological product development for deliverables currently in the pipeline and which are, or can be, targeted at meeting specific exploration requirements. Some of these products, such as countermeasures which mitigate biomedical risks, have long lead times toward maturation and operational integration to satisfy medical standards and requirements.[3] ISS also provides a critical resource to define requirements for exploration needs and for on-orbit check-out of select technologies for the CEV and requisite interfacing with the human system.

Human flight testing may be required for many months, or even years, given current design reference missions to Mars which potentially expose humans to microgravity for periods well in excess of current ISS mission durations. Thus, to adequately test systems and reduce risk of failures, there may well be a need to maintain the ISS, perhaps with commercial and increased partner support, beyond those times currently being proposed.

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[2] *Radiology* 2005; 234(2):319-322. The study involved a collaboration between the ISS increment 9 crew, academia (MI) and industry (TX). The results have implications for assessing physiological adaptation to long-duration microgravity exposure and for remote medical imaging by non-medical personnel in harsh environments, including space and war zones.

[3] A NSBRI bedrest study in spinal cord injury patients has demonstrated the effectiveness of a single infusion of a bisphosphonate medication to inhibit bone loss for a one-year period (MD). The countermeasure requires further evaluation but is promising to counteract bone loss on exploration missions, as well as having potential benefit for the bone loss and fracture risk of persons immobilized by spinal cord or brain injury, stroke, or neuromuscular or developmental disorders.

Not all highly meritorious scientific research and development, engineering and operational systems for human exploration require ISS resources.[4] It will be a challenging yet necessary task to prioritize the advanced space technologies, capabilities and knowledge requiring the ISS as a test bed for exploration. What do we need to do that can only be done on the ISS? What is feasible, given cost, schedule and task? What is the cost of not pursuing certain ISS scientific inquiries given the opportunity? What are the benefits to life on earth from enabling technologies developed for exploration and validated aboard ISS?

The ISS is a training and educational platform for crew to familiarize themselves with the space environment and operational demands for extended periods of time. The path toward exploration class human space missions is invigorating and captures the imagination. It adds to the marvelous recent successes of NASA's robotics program, and if properly executed with integration of the unique capabilities of the ISS, can further inspire the next generation of space scientists, engineers and explorers. Fostering a broad interest in science and engineering is essential to our national mission and well-being, and a strong future workforce in technology helps fuel our economy.[5]

Possible Management Transition Opportunities that Increase Private Sector Involvement in the ISS

There are several management models which may increase private sector involvement in the ISS, such as the proposed ISS Research Institute considered by NASA approximately two years ago. With increased emphasis for exploration on focused, prioritized requirements, corporate participation, development of new capabilities in stages, and management rigor, it is timely that a discussion of management transition opportunities occur now. Given the integrated nature of ISS and exploration, any business model for private sector involvement for ISS should link to plans for exploration. Key sectors include, but are not limited to, aerospace transport, advanced propulsion, power generation and energy storage, automation and robotics, and materials.

The following comments pertain to a management opportunity for ISS biomedical research and countermeasures for human exploration. In 1997, NASA awarded a competitive cooperative agreement to the National Space Biomedical Research Institute to "lead a national effort for accomplishing the integrated, critical path, biomedical research necessary to support long-term human presence, development, and exploration of space and to enhance life on Earth by applying the resultant advances in human knowledge and technology acquired through living and working

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[4] For example, a rugged, portable, lightweight radiation detection instrument is under development by NSBRI/NASA and the United States Naval Academy (MD) to enable real-time measurement of radiation risk in space and estimate risk of damage to body tissue. A preliminary version is scheduled to launch September 2006 on a MidSTAR-I spacecraft. The instrument is applicable on Earth for homeland security, jobs with high potential for radiation exposure and monitoring radiation as part of cancer radiotherapy. A post-doctoral student at Memorial Sloan-Kettering Cancer Center (NY) is working on the cancer application.

[5] Between 1998 and 2002, the number of science and engineering doctoral degrees awarded to U.S. citizens at U.S. institutions fell 11.9 percent to 14,313, according to the Commission on Professionals in Science and Technology, a nonprofit research group.

in space."[6] The NSBRI is a private, non-profit organization that engages scientists and engineers from approximately 70 universities across the country to work on teams to develop countermeasures to health-related problems and physical and psychological challenges men and women face on long-duration space flights. The product-oriented approach to research and development, which is primarily ground-based, is leading to a number of operationally relevant countermeasures now ready for testing and evaluation aboard the ISS. A number of projects have industry partners. The Institute works with an Industry Forum and User Panel, and there is strong program oversight and management rigor, to maximize the likelihood of success and return on investment.

NSBRI engages NASA and other stakeholders throughout the countermeasure development process. This ensures requirements are in place and met, and that the highest priorities of risk are addressed and reduced. Projects are openly solicited and competitively awarded. There is synergy among science and technology projects, as well as integration with an educational program that spans from kindergarten to undergraduate and graduate levels, to post-doctoral training. The NSBRI is productive, cost-effective, scalable and provides NASA with an opportunity to partner with non-government entities to utilize ISS for exploration goals and provide maximum return on valuable resources invested.

In closing, it is recognized that difficult decisions must be made to enable a bold, sustained and affordable space program. ISS presents an unprecedented opportunity to test and validate critical technologies for human exploration and to bring to light the innovative discoveries that advance our nation and civilization.

[6] NASA Cooperative Agreement Notice 9-CAN-96-01.

National Space Biomedical Research Institute
Select Program Accomplishments/Earth Implications

Background

The National Space Biomedical Research Institute (NSBRI), funded by NASA, leads a research program to develop countermeasures, or solutions, to the health-related problems and physical and psychological challenges men and women face on long-duration spaceflights. The research results and medical technologies developed have impact for similar conditions experienced on Earth, such as osteoporosis, muscle wasting, shift-related sleep disturbances, balance disorders, and cardiovascular and immune system problems.

Select Program Highlights

Needle-Free Blood and Tissue Measurement Sensor Progresses to NASA Evaluation

This patented NSBRI device allows accurate, noninvasive blood and tissue measurements not impacted by body fat or skin color. An extension of this work, in collaboration with NASA Johnson Space Center, will adapt the sensor for monitoring in-flight functional changes during exercise and assessing injury. This type of lightweight, portable device will be of use in ambulances, intensive care units and on the battlefield. Another Earth benefit is its ability to detect, without a needle, reduced blood flow in diabetics. (Massachusetts and Texas)

Blue Light: Potential Use for Sleep and Circadian Rhythm Disruptions

NSBRI researchers have discovered that certain wavelengths in the blue portion of the visible spectrum alter melatonin production, thereby affecting the human circadian pacemaker. "Blue light" lamps are predicted to be more effective for regulating circadian rhythm than those currently used pre-launch and represent a potential in-flight countermeasure for adaptation to shifts in sleep cycle required by astronauts during spaceflight. NSBRI is working with an industry partner to study further the use of blue light. On Earth, lighting countermeasures developed for spaceflight can be modified for therapeutic or architectural applications and to facilitate adaptation to shift work. (Pennsylvania and Massachusetts)

Ultrasound Training for Non-Physicians

Diagnosing and managing acute health problems is challenging in space and on Earth. An NSBRI project in collaboration with NASA Johnson Space Center is evaluating the use of ultrasound for medical applications during spaceflight. The work has produced successful training sessions and interactive DVD refresher modules so that non-physician astronauts can successfully use ultrasound in remote medical needs for diagnosis of problems. On Earth, this training system could be used for remote-guided medical evaluation under isolated conditions. (Michigan and Texas)

Drug Advances in Evaluation as Countermeasure

NSBRI investigators demonstrated in ground-based simulation studies that the drug midodrine appears to be a promising agent for post-flight orthostatic hypotension (a drop in blood pressure causing light-headedness and fainting upon standing). A significant number of astronauts experience this condition upon return to gravity. This study is now approved for flight investigation. (Massachusetts and Texas)

Zoledronate: Possible Solution for Bone Loss in Space

In studies of spinal cord injury patients, NSBRI researchers demonstrated the effectiveness of a single, 15-minute IV dose of zoledronate in decreasing bone loss over a one-year period. These researchers are collaborating with NASA scientists and flight surgeons to further evaluate and validate the drug as a countermeasure for bone loss on long-duration missions, as well as in individuals subjected to long periods of bed rest. (Maryland and Texas)

Ultrasound Surgery - No Scalpels or Stitches

This NSBRI project on high-intensity, focused ultrasound, known as HIFU, demonstrates the usefulness of this technique to control bleeding, destroy unwanted tissue or tumors, and dissolve kidney stones with pinpoint accuracy. Treatment does not affect surrounding tissue and could one day allow bloodless surgery in space, emergency rooms and on the battlefield. (Washington)

Protein Linked to Muscle Loss

The way in which muscles atrophy during weightlessness in space has similarity with muscle wasting in diseases such as cancer, AIDS and diabetes. NSBRI-funded investigators identified atrogin-1, a muscle-specific protein whose levels go up during muscle atrophy. Recently, studies by this group have narrowed in on the molecular regulator of atrogin-1, a family of proteins called FOXO, thereby making this protein family a potential target for therapeutic approaches to combat muscle loss. (Massachusetts)

Radiology

Evaluation of Shoulder Integrity in Space: First Report of Musculoskeletal US on the International Space Station[1]

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Abbreviations:
HRF = Human Research Facility
ISS = International Space Station
OPE = Onboard Proficiency Enhancement

[1] From the National Aeronautics and Space Administration, Johnson Space Center, Houston, Tex (E.M.F., G.P.); Texas Diagnostic Imaging, Dallas, Tex (D.L.); Departments of Radiology (M.v.H.) and Surgery (K.M., S.A.D.), Henry Ford Hospital, 2799 W Grand Blvd, Detroit, MI 48202; and Wyle Laboratories, Houston, Tex (A.E.S., D.R.H., D.M., S.L.M.). Received September 30, 2004; revision requested October 12; revision received October 14; accepted October 15. Supported by NASA Flight Grant NNJ04HB07A and the National Space Biomedical Research Institute Grant SMS00301. **Address correspondence to** S.A.D. (e-mail: *sdulcha1@hfhs.org*).

Investigative procedures were approved by Henry Ford Human Investigation Committee and NASA Johnson Space Center Committee for Protection of Human Subjects. Informed consent was obtained. Authors evaluated ability of nonphysician crewmember to obtain diagnostic-quality musculoskeletal ultrasonographic (US) data of the shoulder by following a just-in-time training algorithm and using real-time remote guidance aboard the International Space Station (ISS). ISS Expedition-9 crewmembers attended a 2.5-hour didactic and hands-on US training session 4 months before launch. Aboard the ISS, they completed a 1-hour computer-based Onboard Proficiency Enhancement program 7 days before examination. Crewmembers did not receive specific training in shoulder anatomy or shoulder US techniques. Evaluation of astronaut shoulder integrity was done by using a Human Research Facility US system. Crew used special positioning techniques for subject and operator to facilitate US in microgravity environment. Common anatomic reference points aided initial probe placement. Real-time US video of shoulder was transmitted to remote experienced sonologists in Telescience Center at Johnson Space Center. Probe manipulation and equipment adjustments were guided with verbal commands from remote sonologists to astronaut operators to complete rotator cuff evaluation. Comprehensive US of crewmember's shoulder included transverse and longitudinal images of biceps and supraspinatus tendons and articular cartilage surface. Total examination time required to guide astronaut operator to acquire necessary images was approximately 15 minutes. Multiple arm and probe positions were used to acquire dynamic video images that were of excellent quality to allow evaluation of shoulder integrity. Postsession download and analysis of high-fidelity US images collected onboard demonstrated additional anatomic detail that could be used to exclude subtle injury. Musculoskeletal US can be performed in space by minimally trained operators by using remote guidance. This technique can be used to evaluate shoulder integrity in symptomatic crewmembers after strenuous extravehicular activities or to monitor microgravity-associated changes in musculoskeletal anatomy. Just-in-time training, combined with remote experienced physician guidance, may provide a useful approach to complex medical tasks performed by nonexperienced personnel in a variety of remote settings, including current and future space programs.

Supplemental material: radiology.rsnajnls.org/cgi/content/full/2342041680/DC1

Author contributions:
Guarantor of integrity of entire study, S.A.D.; study concepts and design, all authors; literature research, S.A.D. M.v.H.; data acquisition and analysis/interpretation, all authors; manuscript preparation and definition of intellectual content, all authors; manuscript editing, S.A.D., K.M.; manuscript revision/review and manuscript final version approval, all authors

Medical care capabilities for the International Space Station (ISS) and future exploration space missions are currently being defined (1,2). Although rigorous astronaut selection procedures reduce the chance of chronic health problems, acute conditions can occur during spaceflight (3,4). The probability of a crewmember developing a medical condition that may affect their performance or require care may be increased during long-duration or exploration missions.

Radiology

Some alterations in musculoskeletal integrity take place during prolonged exposure to microgravity, despite the generally successful exercise countermeasures (5). Insidious reduction in bone, muscle, and tendon mass that has been observed during spaceflight may heighten the risk of musculoskeletal injury. In addition, strenuous physical work during spacewalks, combined with upper body and arm motion constrained by the current spacesuits, further raises the likelihood of shoulder injury.

The assessment of musculoskeletal integrity is difficult in space because of limited medical training of the crew and a lack of radiographic and magnetic resonance imaging capabilities on either the transport vehicles or the ISS (6,7). However, a multipurpose diagnostic ultrasonographic (US) system is available within the Human Research Facility (HRF) of the ISS. We evaluated the ability of a nonphysician astronaut operator to perform shoulder US by using remote guidance techniques. This report documents the first shoulder US examination ever performed in microgravity of spaceflight.

ASTRONAUT TRAINING

The ability of two nonphysician astronaut crewmembers to perform shoulder musculoskeletal US was evaluated in the HRF of the ISS during ISS Expedition 9. The investigative procedures were approved by the Henry Ford Human Investigation Committee and the NASA Johnson Space Center Committee for the Protection of Human Subjects. Both crewmembers received briefings and acknowledged their informed consent before the mission, as did other human participants.

Astronaut crewmembers attended a 2.5-hour US familiarization session approximately 4 months before this evaluation to include a brief didactic presentation on the basics of US examination and the experiment-specific principles of remote guidance. The crewmembers also participated in a hands-on US session in the Payload Development Laboratory at the Johnson Space Center, Houston, Tex, where they performed abdominal and musculoskeletal US on a human subject via remote guidance from an experienced sonologist (A.S. and D.L., with 15 and 10 years of experience in musculoskeletal US, respectively). The hands-on sessions were designed to closely simulate in-orbit experiments. Real-time US images were transmitted to the remote sonologist, who guided the astronauts through the necessary positioning, probe placement and manipulation, and equipment adjustments to obtain optimal images. Identical remote-guidance "cue cards" were available to the guiding experienced sonologist on the ground and the operator onboard. The cards included keyboard prompts, anatomic reference points, and other essential information to increase remote guidance efficiency.

IMAGING, EVALUATION, AND COMMUNICATION

The ground and in-flight US examinations were both performed with flight-modified HDI-5000 US systems (ATL; Philips Medical Systems, Bothell, Wash) by using high-frequency (5–12-MHz) linear probes. Images were viewed by the operator on a flat-panel monitor and were transmitted simultaneously to remote US-guidance sonologists (A.S., D.L.) via local circuits (ground familiarization session) or through satellite broadband transmission (flight session). Flight communications include a 1.6-second transmission delay due to distance, data relaying, and conversions. Still and video cameras in the U.S. Laboratory module automatically recorded the US session, but recorded images and video were downloaded to the experiment team only after completion of the experiment.

The astronauts were asked to develop specific restraining techniques for both the subject and the operator, which would allow access to the upper arm and shoulder area, provide stability for the examination, allow unrestricted use of the keyboard, and help avoid operator hand fatigue.

The astronaut US operator completed a 1-hour computer-based US "refresher" course by using the Onboard Proficiency Enhancement (OPE) compact disk developed by the evaluation team 1 week before the US session. Information regarding OPE navigation, time on task, and query responses was stored on the ISS computer and was downlinked to the evaluation team before the US session to allow the team to refine the procedure or highlight certain procedural components to facilitate the upcoming US evaluations.

The US session was completed during scheduled Ku-band (video) and S-band (voice) communications. Dynamic US video was routed through the ISS communications system to the Telescience Center at the Johnson Space Center, where the ground-based experienced sonologist viewed the video output from the US machine with near real-time (1.6-second delay) conditions. Two-way audio communication with the US operator was used to guide US probe placement and adjust US device settings.

A full unilateral shoulder musculoskeletal examination was conducted, which included transverse and longitudinal views of the biceps and supraspinatus tendons and the articular cartilage surface. The examination was initiated with the probe positioned at the distal end of the clavicle in a longitudinal attitude. The probe was "steered" with remote experienced sonologist voice commands to achieve the desired images. After acquisition of the four views of the shoulder area, the subject and operator aboard the ISS switched roles, and the examination was repeated.

Examination completeness was evaluated initially by the ground-based experienced musculoskeletal sonologist by viewing the real-time downlinked US video stream. Full-resolution US frames were saved during the examination and were downlinked to the Telescience Center at a later time. These images were subsequently reviewed by an outside musculoskeletal US specialist (M.v.H.) to verify the diagnostic quality of the examination and the ability to exclude injury on the resultant images.

FINDINGS

The astronaut crewmembers used foot restraints and hand pressure to maintain positioning and freedom of movement in the microgravity environment (Fig 1). This positioning technique allowed the subject to help with keyboard adjustments and provided rapid switching of the subject and operator when the examination was complete (Movie 1, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*). No hand fatigue was reported, which had been noted by previous crewmembers who performed abdominal, cardiac, and thoracic US on the ISS, most likely as a result of the additional effort required when restraint is not optimal.

Remotely guided shoulder musculoskeletal US examinations were completed by the two nonphysician astronaut operators in less than 15 minutes each (Movie 2, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*). The downlinked real-time US video stream provided good-quality images of all of the areas of the shoulder that could be used to exclude substantial rotator cuff abnormalities (Movie 3, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*). Full-resolution US

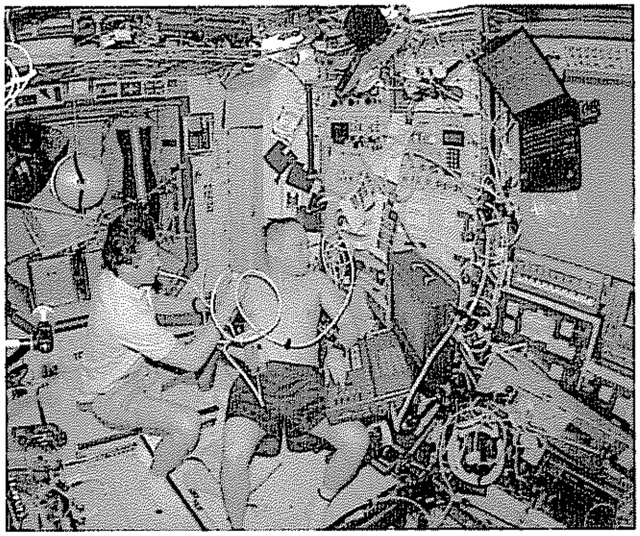

Figure 1. Cabin view obtained with a still camera of the HRF on the ISS. Commander Gennady Padalka performs a musculoskeletal US examination on Mike Fincke by using an HRF US unit (blue flat-screen monitor and keyboard).

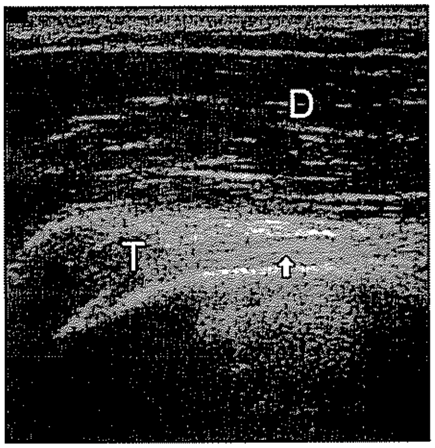

Figure 2. Full-resolution US images of the shoulder were downlinked from the ISS to mission control after the US examination. This image demonstrates a longitudinal view of the biceps tendon. The proximal intracapsular end of the long biceps tendon *(T)* is displayed on the observer's left. Within the normal tendon, a distinct fibrillar pattern is noted (arrow). *D* = deltoid muscle.

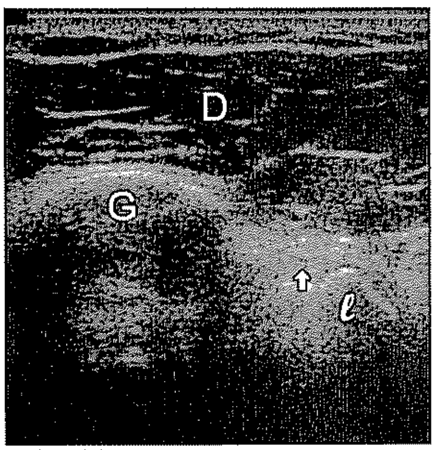

Figure 3. On this transverse view of the extracapsular biceps, the echogenic round shape of the tendon (arrow) is recognized between the lesser tuberosity *(ℓ)* and the greater tuberosity *(G)*. *D* = deltoid muscle.

frames, which were reviewed after the US session by the team, provided excellent-quality detail of all of the shoulder views (Figs 2–5). The still US images could be used to exclude subtle shoulder injury.

DISCUSSION

The ability to provide medical care aboard a spacecraft is challenging because of limitations in crew medical training, medical equipment, and environmental constraints in microgravity (1–5). The crews of the ISS receive training in a wide variety of tasks, ranging from maintaining spacecraft systems to conducting research to performing emergency medical procedures. A crew medical officer, who is generally not a physician, receives approximately 40 hours of additional training in medical diagnosis and therapeutics. Therefore, accurate communication during an illness or trauma is critical, particularly if real-time imaging is to be employed.

US is currently used in many trauma centers to diagnose abdominal injury (8,9). The technique has been shown to be accurate and sensitive in the identification of intraabdominal hemorrhage, even when performed by nonradiologists or nonphysicians (10). NASA investigators have similarly demonstrated that US can be used by nonphysicians to diagnose thoracic injury or bone fracture. The performance of US examinations and interpretation of images for the detection of abdominal bleeding or long-bone fracture do not require extensive training. Conversely, musculoskeletal US is substantially more complex and requires specialized expertise during both data acquisition and image interpretation.

Basic ultrasonic imaging has been completed on both U.S. and Russian spacecraft (5,11,12). NASA investigators have demonstrated a wide array of diagnostic US applications in microgravity experiments on animal models and human volunteers during parabolic flight on KC-135 aircraft. Results of these investigations suggest that the sensitivity and specificity of these US applications are not degraded in microgravity and may even be enhanced in certain circumstances. More comprehensive US examinations (eg, abdominal, musculoskeletal, and cardiac) require considerably more operator experience to perform and interpret autonomously. Since extensive US training with frequent refresher practice is not feasible in many situations, including remote medicine or the space program, alternative paradigms of US examination are required for this application.

Remote US guidance by experienced sonologists virtually couples a modestly trained US operator with a remote sonologist. The US operator is trained in basic US operation and gross requirements of the US examination. The operator places the US probe in a predetermined and familiar starting point (aided by topologic reference cue cards), and the video stream from the US device is split between the on-site monitor and a remote location, where it is viewed by the experienced sonologist. Optimal probe position and device settings are guided with voice commands from the remote sonologist to obtain the necessary US images.

The remote guidance paradigm substantially reduces initial and refresher operator training requirements and allows experienced sonologist input during the conduct of the examination. We combined remote guidance with a focused review of complex US to complete the shoulder musculoskeletal examinations. The unique software used for OPE evaluation in this project streamlined equipment setup and subject and operator positioning and facilitated the successful completion of the complex US tasks by means of remote guidance. This "just-in-time" training approach allowed preflight and in-flight training time to be reduced substantially. The OPE program was constructed in modules that allow future HRF refinements or equipment alterations to be modified electronically as required. The program also can be used as a framework for other complex tasks that require focused skills or complex instructions. The self-reporting feature of the program allowed the experienced sonologists on the ground to assess operator familiarity with the procedures to better prepare for and conduct the session.

The evaluation of shoulder integrity with the use of US is the standard of care at many institutions and is used by professional athletic teams to evaluate injuries to athletes. Astronaut crewmembers may be at risk of shoulder injury during long-duration spaceflight because of decreases in muscle and tendon mass and exertion during space walks. The extravehicular activity suits that are worn constrain upper body and arm movement. Construction requirements on the ISS and future exploratory missions involving extravehicular activities can increase strain on the shoulder joint. A reliable method for evaluation of shoulder integrity during long-duration space missions would increase medical care capabilities for this operationally relevant concern.

Shoulder musculoskeletal US was performed rapidly and accurately by the two astronaut crewmembers aboard the ISS. The average time to perform the examination was less than 15 minutes. The conduct of the examination was not appreciably different than similar examinations in a terrestrial environment and was aided by innovative restraint techniques developed by the crewmembers (Movie 4, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*). The quality of the near real-time US video transmitted to the Telescience Center was very good and could be used to exclude substantial shoulder musculoskeletal injury. Still US images were obtained during the examination and were downlinked to the team afterward. These high-fidelity images were of excellent diagnostic quality and could be used to exclude subtle changes in shoulder integrity.

The ability of the ISS crew to perform complex US tasks aboard the ISS supports the hypothesis that a nonphysician crewmember with modest training in US can perform high-fidelity diagnostic-quality examinations when directed by a ground-based experienced sonologist. The images acquired by the astronaut in this study were of excellent content and quality, and in a "real" medical scenario, they would have provided essential information to guide clinical decision making. There were no discernible differences between the US examinations performed in orbit and those performed in standard terrestrial conditions when the images were evaluated by the experienced sonologists involved in this trial.

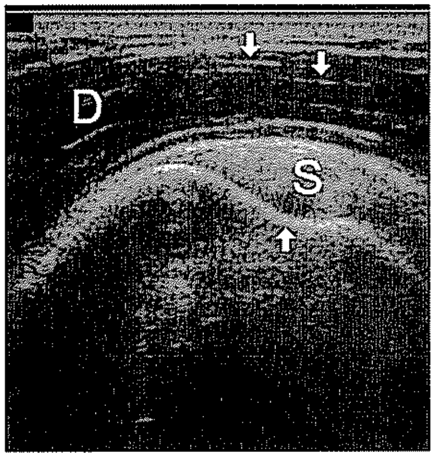

Figure 4. With the transducer placed over the long axis of the deltoid muscle *(D)*, note the longitudinal striations (upper arrows) of the fibrofatty septa in between the muscle bundles. Supraspinatus tendon *(S)* is displayed in its long axis deep to the deltoid. The tendon rests on the bright echogenic surface of the proximal humerus. The humeral head shows on the medial aspect (observer's right) and the greater tuberosity more laterally. The anatomic neck is recognized on the groove (lower arrow) between these bone surfaces.

The optimal training of crewmembers for the ISS and later exploration-class missions is still being defined. This initial US experience suggests that limited training, combined with onboard proficiency enhancement 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 probably be the case in most terrestrial situations, such as in some remote and most military settings.

The unique constraints imposed by the space environment require the development of detailed training, diagnostic, and therapeutic strategies. Although some of the aerospace procedures currently investigated by NASA are appropriate only for the space environment, many other spaceflight-derived techniques are readily transferable to the Earth, including rural, military, and emergency medical care. 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, with profound ramifications for emergency or clinical medicine (Audio 1, *radiology.rsnajnls.org/cgi/content/full/2342041680/DC1*).

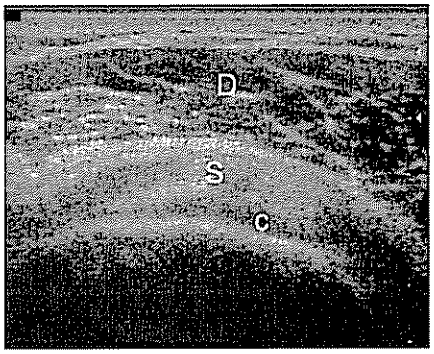

Figure 5. With the transducer turned perpendicular to the position in Figure 4, the examination of the supraspinatus *(S)* is completed with transverse views of the cuff. The deltoid muscle *(D)* is separated from the supraspinatus by alternating hypo- and hyperechoic lines, representing bursa and peribursal fat. The echogenic supraspinatus rests on hypoechoic hyaline cartilage over the echogenic humeral head surface *(c)*.

References

1. Davis JR. Medical issues for a mission to Mars. Aviat Space Environ Med 1999; 70:162–168.
2. Grigoriev AI, Egorov AD. The theory and practice of medical support of long-term space missions. Aviakosm Ekolog Med 1997; 31:14–25. [Russian]
3. NASA. Medical intervention and care. ISS Medical Operations Requirements Document SSP 50260, clause 4.1. Rev B ed. Houston, Tex: NASA, 2003.
4. Grigoriev AI, Bugrov SA, Bogomolov VV, et al. Medical results of the Mir year-long mission. Physiologist 1991; 34(suppl 1):S44–S48.
5. Gazenko OG, Shul'zhenko EB, Grigor'ev AI, At'kov Olu, Egorov AD. Medical studies during an 8-month flight on the orbital complex "Saliut-7"—"Soiuz-T". Kosm Biol Aviakosm Med 1990; 24:9–14. [Russian]
6. Harris BA Jr, Billica RD, Bishop SL, et al. Physical examination during space flight. Mayo Clin Proc 1997; 72:301–308.
7. Sargsyan A. Medical imaging. In: Barratt MR, Pool SL, eds. Principles of clinical medicine for space flight. New York, NY: Springer Verlag, 2003.
8. Patel JC, Tepas JJ 3rd. The efficacy of focused abdominal sonography for trauma (FAST) as a screening tool in the assessment of injured children. J Pediatr Surg 1999; 34:44–47; discussion, 52–54.
9. Scalea TM, Rodriguez A, Chiu WC, et al. Focused assessment with sonography for trauma (FAST): results from an international consensus conference. J Trauma 1999; 46:466–472.
10. Boulanger BR, Kearney PA, Brenneman FD, Tsuei B, Ochoa J. Utilization of FAST (Focused Assessment with Sonography for Trauma) in 1999: results of a survey of North American trauma centers. Am Surg 2000; 66:1049–1055.
11. Atkov OYu, Bednenko VS, Fomina GA. Ultrasound techniques in space medicine. Aviat Space Environ Med 1987; 58(9 pt 2):A69–A73.
12. Jadvar H. Medical imaging in microgravity. Aviat Space Environ Med 2000; 71:640–646.