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The International Space Station Ultrasound Imaging Capability Overview for Prospective Users

Ashot E. Sargsyan, M.D.
Douglas R. Hamilton, M.D.
Shannon L. Melton
Jeffrey Young

Wyle Laboratories, Life Sciences Group
NASA Johnson Space Center, Houston, Texas

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Acknowledgments

This publication draws together the knowledge in the area of ultrasound imaging on the International Space Station (ISS) accumulated in the initial several years of its piloted operation. Our respect and appreciation also goes to the teams that designed, created, and deployed the ISS Human Research Facility (HRF) Ultrasound System. The authors also recognize with gratitude the work of those who carried out ultrasound imaging experiments in the pre-ISS space programs; their unique experience will always retain its great value for the space biomedical science and clinical space medicine.

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Today's robust imaging capability aboard the ISS and the knowledge it generates attest to the talent and expertise of these individuals and to their unending dedication to human space exploration and utilization.

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Contents

Figures

Tables

Acronyms

ADUM	Advanced Diagnostic Ultrasound in Microgravity
ATL	Advanced Technology Laboratories
ATU	audio terminal unit
BMFC	biomedical flight controller
CAPCOM	capsule communicator
CEVIS	cycle ergometer with vibration isolation system
CHeCS	Crew Health Care System
CMO	crew medical officer
CMRS	Crew Medical Restraint System
DCN	Document Change Notice
DICOM	digital imaging and communications in medicine
DMCF	definitive medical care facility
DVD	digital video disk
DVIS	Digital Voice Intercommunication Systems
ECG	electrocardiogram
ESS	experiment support scientist
ETT	endotracheal tube
FAST	focused assessment with sonography for trauma
FCOH	Flight Controller's Operations Handbook
FS	flight surgeon
FSD	flat screen display
FTP	file transfer protocol
GC	ground control
HMS	Health Maintenance System
HRF	Human Research Facility
IMG	Integrated Medical Group
IMS	Integrated Medical System
ISS	International Space Station
JSC	Johnson Space Center
MCC	Mission Control Center
MCC-H	Mission Control Center-Houston
MMOP	Multilateral Medical Operations Panel
MOD	Mission Operations Directorate

MORD	Medical Operations Requirement Document
MPSR	Multipurpose Support Room
MSFC	Marshall Space Flight Center
MSL	Medical Simulation Laboratory
NRT	non real time
OCA	orbiter communication adapter
OPE	on-board proficiency enhancement
PDL	Payload Development Laboratory
PHHU	portable, hand-held ultrasound
PID	pelvic inflammatory disease
POH	Payload Operations Handbook
RDCS	Registered Diagnostic Cardiovascular Sonographer
RDMS	Registered Diagnostic Medical Sonographer
RVT	Registered Vascular Technologist
S/G	space-to-ground
SODF	Station (Systems) Operations Data File
SOL	space-occupying lesion
SSPCM	solid-state power control module
TSC	Telescience Support Center
US	ultrasound
UTMB	University of Texas Medical Branch
VOX	voice activation mode
VPPI	visceral-parietal pleural interface

Executive Summary

Prior success of ultrasonic imaging in space flight and promising research opportunities motivated the inclusion of an ultrasound system in the Human Research Facility (HRF) aboard the International Space Station (ISS). Since its delivery by the STS-102 space shuttle mission and subsequent activation by the ISS Expedition 2 crew in June 2001, 101 hours of successful imaging operations have been logged (17.5 hours for ISS medical operations experiments and 83.5 hours for research by non-NASA investigators as of September 2006). Multipurpose ultrasound devices of this model (Advanced Technology Laboratories/Phillips HDI-5000, Bothell, Wash.) are used worldwide for both clinical and research purposes. The HRF Ultrasound System represents a significant advance in space-based medical imaging, surpassing any previously flown ultrasound system in image quality, versatility, and data handling.

Ultrasound imaging events require extensive planning and coordination, as well as real-time support. The ISS ultrasound system is activated, configured, and operated through a coordinated effort by multiple Mission Control Center console positions and the ISS crew, using validated procedures and various resources and assets.

Space Medicine and the HRF conducted a successful demonstration of the ISS ultrasound imaging capability in September 2002 during ISS Expedition 5. This event was initiated by Space Medicine to validate the configuration for real-time data transmission and the concept and tools for real-time remote guidance for complex imaging tasks for medical (operational) purposes. Using a restricted video downlink and two-way private audio, an ultrasound expert on the ground verbally guided the crew member through a series of sample imaging protocols with multiple thoracic (heart and lungs), abdominal, and other anatomical sites. This session established a foundation for subsequent development and validation of an effective scheme for ultrasound imaging aboard the ISS using crew members without professional medical experience.

NASA and all ISS Partners, through the ISS Multilateral Medical Operations Panel, have recognized the HRF Ultrasound System as a clinical diagnostic resource to augment the ISS Integrated Medical System in case of a medical contingency. Recognition of the system's operational potential is based on terrestrial evidence and experiments conducted by NASA and other investigators before and during the ISS Program in conditions of ground laboratories, parabolic flight, and space flight. As in mainstream terrestrial medicine, objective imaging data can optimize illness/injury management and outcome and minimize mission impact (e.g., avoiding unnecessary medical evacuation). Consequently, the ISS Program adopted a requirement that ultrasound imaging capability be available for medical contingencies aboard ISS. Internal NASA documents have been created to define the use of the HRF Ultrasound for augmentation of the ISS medical care capability.

This publication seeks to review existing knowledge and define the principles and solutions for the use of ultrasound imaging on the ISS for either research or medical purposes.

1. Introduction

The feasibility of ultrasonic imaging in human space flight has been demonstrated on NASA and Russian spacecraft. Several ultrasound systems have been successfully operated by both physician and non-physician astronauts and cosmonauts in pre-International Space Station (ISS) space flights, yielding valuable scientific information. A multipurpose ultrasound system was adapted for space and installed aboard ISS to continue human research in microgravity environments at a new level of sophistication and fidelity. Alone or in combination with other components of the Human Research Facility (HRF), the system provides a research capability never before available in space.

The system is equipped with hardware components, transducers, and software to generate high-definition images in all conventional modes used for cardiac, vascular, general/abdominal, thoracic, musculoskeletal, and other ultrasound applications. Specifically, the system can operate in B, M, Color Doppler, Power Angiography, Flow Propagation, Pulsed Spectral Doppler, and Continuous Wave Doppler modes and their combinations. The system may be upgraded to add Tissue Doppler mode to the above list. Thus, the HRF Ultrasound System allows the realization of the great scientific potential of ultrasound imaging in conditions of space flight, acquiring morphological/morphometric as well as physiological/functional information from virtually every area or organ system of the human body.

Ultrasound has never been used in space for the purpose of medical risk mitigation; its use has been limited to feasibility demonstrations or research. However, the potential of the HRF Ultrasound as a diagnostic tool for space medicine activities has been recognized. The ISS Integrated Medical System (IMS) was originally designed for use in concert with a vehicle that has capabilities to evacuate an ill or injured crew member to a definitive medical care facility (DMCF) on Earth. Since plans for such a vehicle were discontinued, a mismatch had existed between the on-board medical capabilities and the mission profile. This has driven the medical concept of operations to recognize and treat as many medical conditions as possible while on orbit, with return to a DMCF delayed or avoided. Therefore, enhancement of on-orbit diagnostic and treatment capability is highly desirable. The IMS includes NASA (Crew Health Care System (CHeCS)) and Roskosmos medical equipment. In addition, Medical Operations can claim any other ISS asset that is deemed necessary to manage a medical contingency. The HRF Ultrasound System is an example of such assets.

In the ISS setting, with no other imaging methods available, the full diagnostic potential of ultrasound could be exploited to assist in managing a medical event on orbit. However, it is not practical to train crew members and maintain their proficiency for performing ultrasound imaging independently.[1] *Therefore, the authors consider real-time guidance by an expert from the Mission Control Center (MCC) as the primary means for a minimally trained crew member to capture clinically useful images. The essential data acquisition expertise resides on the ground and is provided to the operator during the examination as needed.* Preliminary assessment and interpretation of data can be performed in real time. Detailed data analysis and generation of an imaging report for clinical purposes (or data analysis for research purposes) are performed

[1]In the U.S. and Canada, certified sonographers are specialized in sub-disciplines such as abdominal, cardiac or vascular ultrasound. Generally, two-year full-time education and a year of experience (or completion of an ultrasound school) are prerequisites for a registry examination. To maintain the credential, Continuous Education credits must be regularly demonstrated (www.ardms.org). In the Russian Federation, most of Europe, and Japan, ultrasound imaging is performed by physicians.

through post-examination review of the video and still images, either by a physician properly credentialed and licensed for the given type of the clinical study or by the investigator(s). The paradigm of remote guidance, though unconventional for mainstream imaging services, is also applicable to certain terrestrial settings where remote provision of imaging expertise may translate into improved outcomes and cost savings.

NASA and all ISS Partners through the Multilateral Medical Operations Panel (MMOP) have officially recognized the HRF Ultrasound imaging system as a strategic clinical diagnostic resource to augment the IMS in case of medical contingency.[2] This recognition is substantiated by terrestrial evidence, parabolic flight and space flight experiments, ISS-based demonstrations, and more recent end-to-end validations conducted by NASA. As a result, ultrasound imaging is officially included in the ISS medical requirements. This publication could contribute to the implementation of the above requirement, as it includes a comprehensive operational concept with implementation solutions for ultrasound imaging aboard ISS for medical or science purposes.

The HRF Ultrasound was successfully activated aboard the ISS on June 12, 2001. NASA Space Medicine conducted an end-to-end demonstration of the entire ISS Ultrasound System during Expedition 5 (Sept. 13, 2002), and validated the principle and the basic techniques of remotely guided ultrasound imaging for crew medical support. For the first time, real-time video from the

Figure 1. Astronaut Peggy A. Whitson, Expedition 5 NASA ISS science officer, participates in a test to validate the use of the HRF Ultrasound System for potential medical contingencies.

[2]This consensus determination of the ISS MMOP was made on March 13, 2001.

ultrasound system was routed to the MCC. Using a video downlink and a two-way private space-to-ground (S/G) audio, an ultrasound expert on the ground remotely guided the crew member through multiple scanning sequences (figure 1). As a result of this activity, a set of formal space and ground operational procedures was created and validated. NASA Medical Operations, jointly with HRF, conducted subsequent on-orbit ultrasound activities during ISS Expeditions 6 and 7 to validate space echocardiography protocols, demonstrate stress echocardiography on orbit, and conduct focused image quality assessments.

An external investigator's operationally oriented experiment, "Advanced Diagnostic Ultrasound in Microgravity (ADUM)," was performed during ISS Expeditions 8, 9, 10, and 11 to thoroughly examine and upgrade the ISS imaging utility (Principal Investigator - Dr. Scott A. Dulchavsky). The ADUM experiment identified possible improvements to the methodology of real-time remote guidance, explored the capabilities and limitations of the system for a number of new applications, and substantially enhanced the training component. These and other activities are listed in Appendix 7 of this document.

The goal of this publication is to define the principles and current solutions for the use of remotely guided ultrasound imaging on ISS for research or medical purposes.

2. Objectives

The primary objectives of this publication are to define

- Principles of ultrasound imaging on ISS with real-time remote guidance, with an emphasis on imaging support in the management of complex scientific tasks or contingency medical situations.
- Composition and configuration of the ISS Ultrasound System, including
  - HRF Ultrasound and associated on-board and ground-based elements.
  - Hardware configuration, accessories, supplies, and other material assets necessary to conduct ultrasound imaging on ISS.
  - Communication assets necessary to conduct ultrasound imaging aboard ISS.
  - Ground infrastructure necessary to conduct ultrasound imaging aboard ISS.
- Essential ground support personnel.
- Training, knowledge, and skill sets of each ground support position/personnel necessary to conduct ultrasound imaging on ISS.
- Crew knowledge, skill sets, and associated training needed for ultrasound imaging on ISS.
- Feasible ultrasound applications available to the user (an investigator or a flight surgeon) categorized into the following three groups:
  - Complete (Standard) Exams (noninvasive, generally considered available),
  - Focused and Limited Studies (noninvasive, generally considered available), and
  - Image-Guided Manipulations (invasive, require consultants and special consideration due to the possibly higher risk of discomfort, failure, or iatrogenic complications).
- Feasible on-board techniques and configurations for ultrasound data acquisition.
- Pertinent documentation relevant to ultrasound imaging on ISS.
- Supporting evidence, such as a summary of ISS ultrasound imaging events to date and a list of available sources of information (HRF, Medical Operations, and research community).
- A list of relevant publications.

3. Assumptions and Conditions for Operational (non-research) Imaging

As part of the HRF, the ISS Ultrasound System is flown on ISS for research purposes. The science/payload community therefore drives HRF configuration, support, and availability. HRF resources are allotted for scheduled payload activities, and HRF support is provided per schedule or via the increment-specific call tree for unscheduled events.

An assumption is made that the in-flight caregiver (crew medical officer (CMO) or a designee if the CMO is the ill/injured party) is not a physician or other health professional, and does not possess current clinical expertise or ultrasound imaging skills and knowledge beyond those retained from the standard training (including ultrasound familiarization and CMO training).

ISS Medical Operations would use the system for clinical purposes if the following conditions were met:

1. The crew surgeon determines that an ultrasound imaging examination is clinically indicated and requests specific ultrasound applications to be performed.

2. ISS Medical Operations is granted preferential access to the necessary space and ground resources, including the HRF Ultrasound System and the U.S. Orbital Segment communication assets. This assumption is supported by the existing ISS documentation.

3. HRF and other essential support personnel are available at their console positions to initiate and maintain HRF rack commanding and to support HRF Ultrasound operation, data processing, and transfer. A contact list is maintained through specific agreements between Medical Operations and HRF.

4. An ultrasound expert is available to obtain the imaging data by providing, in close coordination with the crew surgeon, real-time remote guidance of the crew member operator, using restricted/private communications to support a live video downlink and two-way S/G audio.

4. Fundamental Principles

The fundamental principles of ultrasound imaging aboard ISS are listed and explained in the following paragraphs.

4.1. Balanced Expertise and Knowledge Distribution

A robust set of skills and knowledge is essential for ultrasound imaging. In the case of the ISS Ultrasound System, the necessary information and expertise are distributed among ground- and space-based sources. Elements of this expertise are claimed/transferred as needed to perform a clinically indicated imaging procedure.

Astronauts with diverse backgrounds are not expected to possess skills for specialized medical or science activities such as ultrasound imaging. Proficiency in this highly complex and operator-dependent task cannot be attained without thorough formal training and hands-on experience, neither of which is feasible or practical in case of on-orbit personnel. Limited knowledge and skills acquired for prior or current science activities cannot be fully retained throughout the time interval between training and actual on-orbit demand. Consequently, acceptable efficiency and quality of the given imaging application on orbit can be achieved only through optimized distribution of necessary expertise among space and ground personnel.

The limited preflight training provides crew members with substantial hardware familiarity and general knowledge of principles, positioning, restraints, safety, and microgravity human factors. Crew members should also undergo a remotely guided practice session in the high-fidelity simulator (Payload Development Laboratory (PDL) to experience a full range of activities associated with the imaging procedures, to develop realistic expectations, and to minimize anxiety for future ISS ultrasound activities. All remaining knowledge (i.e., most of the general imaging procedure and the entire base of specific application protocols) "remains" on the ground and is provided by the guiding expert(s) as needed through

(a) limited pre-session instruction uplinks.
(b) referring to specific on-board information resources in real time.
(c) real-time voice instructions.

A significant amount of pertinent information (also considered part of "distributed expertise") resides in the ISS Medical Checklist and the Station (Systems) Operations Data File (SODF). Also, HRF has a multimedia ultrasound training program called "On-Orbit Proficiency Enhancer" on board as a just-in-time training and refresher tool. This program was developed as experiment-unique software and manifested on ISS by the operationally oriented research experiment ADUM. If needed, a user can request use of this tool in the planning phase of the ISS Ultrasound System activation. Such a decision would be made on a case-by-case basis. Other ground-based reference and instructional materials are available for selective uplink at the discretion of imaging experts, investigators, consultants, and the crew surgeon. Careful selection and timing of these information deliveries creates an essential intermediate link between the preflight training, equipment operating procedures and on-board documentation, and remote guidance during actual imaging procedures.

4.2. Experimental Nature and Limited Evidence (applicable in clinical (non-research) use)

Controlled trials have not been conducted to determine the accuracy of diagnostic ultrasound in special operational settings such as ISS; therefore ultrasound imaging aboard station must be considered experimental in nature, notwithstanding prior successes in demonstrations and research. Specific applications in microgravity for any clinical purposes may be supported by evidence that is purely anecdotal, partial, or indirect, or by expert opinion derived from terrestrial experience, microgravity simulations, or on-orbit experiments and demonstrations. No pathological conditions and only limited physiological alterations have been documented by ultrasound during space flight. Microgravity-induced physiological circumstances and the potential alterations of pathological processes may not be known or applicable in a given case. In addition, evidence may be lacking or limited regarding accuracy of a given imaging application in a given case and setting. Some imaging applications suggested in this publication are not routinely practiced even in terrestrial medicine due to above-average complexity, lack of evidence, or the existence of effective alternatives. Furthermore, time constraints and limitations of remotely guided imaging may also affect the quality and completeness of data. For these reasons, Integrated Medical Group (IMG) physicians are expected to consider ISS contingency ultrasound reports in conjunction with information on any preexisting microgravity evidence, actual data quality and completeness, specificity of findings, and estimated probability of false results.

4.3. Shared Resources

- The HRF Ultrasound is flown aboard ISS for research purposes, and its configuration, support and availability are driven by the NASA/ISS payload community. HRF and other non-Medical Operations resources are allotted for specific scheduled payload activities and do not provide for support 24 hours a day/7 days a week. However, if the decision is made to activate the ISS Ultrasound System, essential resources are invoked to configure and operate the system as an enhancement to the ISS IMS. According to existing agreements, Medical Operations assumes all components of the system, including the HRF Ultrasound, to be intact and functional by default unless informed of any failure or outage.
- The Crew Medical Restraint System (CMRS) is approved to be deployed at LAB1D2 (temporary deployment) to support the ISS Ultrasound System. Investigators must request and receive approval for use of this asset in advance.
- The Telescience Support Center (TSC) in the MCC is the nominal facility for the science experiment teams conducting real-time remotely guided ultrasound. This facility will also be used by the HRF support team to carry out rack commanding/monitoring operations for any scientific or clinical purpose, and will coordinate all ultrasound data products obtained during the ultrasound activity. The TSC will also function as the backup location for real-time clinical ultrasound downlink, should the Biomedical Multipurpose Support Room (Biomed MPSR) be unavailable.
- Preflight training can also be a shared resource. Training sessions may be abridged (or waived in rare cases) for crew members having operated the HRF Ultrasound in previous flight(s) or having been trained to a comparable degree for another previous or current ISS experiment. Preflight training involving HRF Ultrasound will be coordinated with HRF to optimize crew time and other resource use through sharing (or mutually crediting) training and practice sessions. Appropriate modifications to enable mutual crediting should be attempted for each Expedition crew.

4.4. Common Reference

The imaging expert on the ground and the ultrasound operator aboard ISS use common sources of reference, terminology, and understanding of the principles of remote guidance.

- ISS astronauts and imaging experts on the ground use identical remote guidance reference cards (also known as “ultrasound cue cards”) to identify anatomical reference points, ultrasound keyboard controls, and probe manipulation techniques.
- In addition to the cue cards, ISS astronauts and the imaging experts on the ground may also use target image reference cards. These image sets are specific for the particular imaging protocol (application), and are provided before the imaging procedure to enhance efficiency of the session.

- Medical, anatomical, or medical-technological terms in English, Latin, Russian, or other languages are replaced by lay terminology whenever possible, or explained with utmost clarity. Medical or medical imaging jargon, acronyms, or concepts that may be unfamiliar to the on-board operator should not be used.

4.5. Identification of Responsibility

The ISS operator and the subject (or patient in a medical scenario) receive explicit disclosure of the goals and objectives of the ultrasound imaging procedure, its limitations, and the roles and responsibilities of ISS and ground personnel. Specifically, the ISS crew must clearly understand that the responsibility for quality and completeness of the imaging results rests with the ground personnel, not with the ISS operator. Disclosures must also be made to the crew regarding the identity of the guiding expert(s) and other personnel to have access to the real-time audio and video as well as to the recorded data. For a scheduled science experiment, this is accomplished through the preflight informed consent briefing. In acute medical scenarios, verbal communications with the crew surgeon are used to ensure compliance with current policies and legal requirements on the one hand, and full consent and understanding by the crew on the other.

4.6. Clinical and Operational Subordination (applicable in clinical (non-research) use)

Ultrasound experts, radiologists, and other imaging-related personnel, whether in-house or external, are operationally subordinated to the ISS crew surgeon (or IMG surgeon on console at the MCC).

Ultrasound imaging studies are ordered by the ISS crew surgeon or an ISS IMG surgeon on console (if the crew surgeon is unavailable) when clinically indicated. The surgeon orders the study, defines its scope, poses specific questions, requests necessary resources from the flight control team, establishes priority and preferred timing of the imaging session relative to other medical activities and decisions, and receives preliminary and final imaging reports.

5. The International Space Station Ultrasound System

From the user's perspective, the ISS Ultrasound System is comprised of space (in-flight) and ground hardware, software, and communication links. The core component of the system is the HRF Ultrasound. It is activated to perform a scheduled research activity (or, upon request of the crew surgeon, a diagnostic study on an ill or injured ISS crew member). The ISS Ultrasound System involves the shared space and ground elements listed below.

5.1. In-flight Hardware Resources

The HRF rack houses the ISS Ultrasound System and, as of September 2006, resides at location ISS Laboratory 1S2 (LAB1S2). It may be necessary to move the rack to accommodate new hardware and new internal ISS configurations as ISS construction continues. HRF will inform all recognized users of such moves so that appropriate procedures and documentation can be updated. Table 1 lists items specific to HRF Ultrasound, as well as the necessary general flight hardware.

Table 1: In-flight Hardware, Accessories, Supplies, and Other Material Assets Necessary to Conduct Ultrasound Imaging

Element	Redundancy	Essential?	Responsible Org(s)	Function/Notes
HRF Rack	N	Y	MSFC; JSC HRF	Location: ISS Lab1S2 Houses the HRF Ultrasound, provides all interfaces.
HRF Ultrasound	N	Y	HRF	Includes main unit (rack-mounted) and stowable components such as keyboard, monitor, cables, and bracket assemblies.
HRF Workstation	Y	Varies	HRF	Not essential for real-time video downlink. Used for image file transfer in DICOM digital format from HRF Ultrasound after examination. HRF laptop is first choice for this function as it requires less crew time to configure. The workstation would only be required if more hard drive space is needed for images captured during the session. Due to HRF rack power constraints,[3] it is not recommended that the ultrasound and workstation run at the same. The decision to use the workstation in lieu of the laptop is made by HRF.
HRF Laptop	Y	Varies	HRF	Not essential for real-time data collection. This is the primary computer for image file transfer from the HRF Ultrasound System to the ground after examination. The HRF workstation can replace the HRF laptop.
CMRS	N	Varies	Medical Operations	Essential or highly desirable in most applications; also required by ISS medical checklist for contingency ultrasound imaging. The area in front of the HRF rack must be cleared for CMRS deployment (LAB1D2).
Remote Guidance Ref. Card (Cue Card)	Y	Y	Medical Operations/ HRF	Hard copy of the cue card is stowed with other detachable components of the ultrasound system. Hardcopy is included in the medical checklist, electronic copy is available in the SODF/medical checklist.
Voice Activation Mode (VOX) Audio Terminal Unit (ATU)	Y	Y	Station support equipment	Voice-activated headset for audio communication with ground expert. Replaces the push-to-talk audio system, allowing the operator to use both hands for the imaging procedure including probe manipulation, keyboard operations, gel application, and stabilization. VOX/ATU must be on a speaker to allow both the operator and the subject (or the patient) to hear commands from ground experts.
PD100 (camcorder)	Y	N	ISS	To capture cabin scene. The data are downlinked in non real time (NRT) to support data analysis.
Electronic Camera Electronic Still Camera	Y	N	ISS	To capture cabin scene. The data are downlinked NRT to support data analysis.
ECG Electrodes	Y	Varies	Medical Operations	For cardiac applications. Scientist users may require ECG for other research protocols to meet data collection objectives.
Ultrasound Contact Gel	N	Y	HRF and Medical Operations	A TBD minimum amount is maintained on board for contingency support. Each experiment should develop and coordinate projections. Material safety data sheets and other details are available from HRF.

[3]The HRF rack was designed with multiple solid-state power control modules (SSPCMs), to accommodate powering all equipment. One SSPCM has failed and is not currently scheduled to be replaced; therefore, additional power constraints apply.

5.2. Communication Assets

5.2.1. *Commanding*

- S-band: to command rack configuration and deconfiguration.
- S-band: to send commands to initiate downlink of full-resolution digital images after examination (still and cine-loop).

5.2.2. *Data management, uplink/downlink*

- Ku-band
  1. Restricted[4] real-time video, 15–30 frames per second (fps) of ultrasound video for real-time session management and remote guidance, routed to the Biomed MPSR (Medical Operations).
  2. Data collection: digital files of images captured in the ultrasound system are downlinked to HRF and then made available to the user (investigator(s) or Medical Operations at the Biomed MPSR) on removable media or via secure electronic transfer. Data are compliant with the DICOM [digital imaging and communications in medicine] standard and require a DICOM reader for viewing.
  3. Cabin view video downlink post session.
  4. Cabin view still image downlink post session.
  5. Pre-session file uplink through the orbiter communication adapter (OCA).
  6. Target image cards or other relevant illustrations, text instructions, and safety precautions can be provided for uplink through the HRF experiment support team (research).

- S-band
  1. Private real-time two-way audio for real-time session management and remote guidance, routed to Biomed MPSR (Medical Operations).
  2. Target image cards or other relevant illustrations, text instructions, and safety precautions can be provided for uplink through the HRF experiment support team (research).

- Ground recording
  1. Real-time video downlink from the HRF rack/ultrasound system with the real-time private audio track is recorded in digital format, and made available to the user on removable media (digital video disk (DVD) by default).
  2. Cabin view video downlink is recorded in digital format, and made available to the user on removable media (DVD by default).

5.3. Ground Infrastructure, Locations, Positions, and Assets

Table 2 contains a consolidated list of the ground assets necessary to conduct a remotely guided ultrasound imaging session on ISS. The one-way video feed and the two-way private audio loop are also included in the table.

[4] Access to real-time video is restricted as the information contained therein is always private/confidential, as well as proprietary (research).

Table 2: Ground Infrastructure, Hardware, Accessories, Supplies, and Other Material Assets Needed for ISS Ultrasound

Element	Redundant?	Essential?	Responsible Org.	Function/Notes
Restricted video feed	Y	Y	GC	Restricted video to TSC or Biomed MPSR. There is only one restricted video feed to the above locations; however, additional video such as cabin video could be downlinked simultaneously. Two video feeds would require using half the maximum frame rate available.
Private S/G audio loops	Y	Y	Houston TV	Private S/G configured on TSC or Medical Operations consoles.
Video and Audio Recording Capabilities	Y	Y	TSC or Biomedical Flight Controller (BMFC)/ Mission Operations Directorate (MOD)	Video and audio can be recorded by the end-user in the Biomed MPSR, or by JSC Imagery Services. Note: JSC Imagery Services does not support 24/7 operations; it is nominally staffed on weekdays, first shift only. Special request is made for an off-nominal situation.
Video Monitor	Y	Y	TSC or BMFC	Flat screen, low-glare, high-fidelity monitor for video; required to view ultrasound video.
Digital Voice Intercommunication Systems (DVIS) Station	Y	Y	TSC or BMFC	At least one (in addition to crew surgeon and BMFC stations) DVIS station is needed to conduct clinical ultrasound.
Ultrasound Reference Image[5]	Y	Y	TSC or BMFC	There are multiple copies of the ultrasound reference images, a hard copy in the Ultrasound Console Handbook, and an electronic copy in onboard documentation.
DVIS Headsets	Y	Y	TSC or BMFC	Additional DVIS headsets for personnel supporting ultrasound operations such as the remote guidance expert.
Timer	N	N	TSC or BMFC	A timer helps the remote guidance expert in time management during scanning.
DICOM viewer Software	Y	Y	Remote Guidance Expert	DICOM viewing software is needed to view the captured images downlinked from the HRF Ultrasound.

[5]The Ultrasound Reference Image is similar to a cue card with an anatomical reference chart, a color-coded HRF Ultrasound keyboard image, and a probe manipulation illustration

6. Essential Ground Personnel

A broad, closely coordinated involvement of multiple control positions and personnel at the Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC) is necessary for the proper configuration and use of the system. Depending upon circumstances and availability, a control position may be supported by one or more individuals (personnel). HRF personnel listed in this section, including specific HRF console positions, are considered essential ground personnel. For performing clinical ultrasound imaging on ISS, the crew surgeon, BMFC, and remote guidance expert are considered essential Medical Operations ground personnel. For a research activity with real-time guidance, a remote guidance expert is considered essential. Main positions, roles and responsibilities, relevant training and experience, and respective information resources for the above individuals are listed in this section.

Other personnel, such as the flight director, capsule communicator (CAPCOM), telescience operations personnel, or ground control (GC) are not specific for ultrasound operations, but are required to allot crew time, communicate procedures to the crew, and configure ground resources. These positions do not require specific knowledge or training for their roles related to clinical ultrasound imaging operations, and can be briefed as necessary by the user's personnel.

6.1. Crew Surgeon (if imaging is for medical purposes)

6.1.1. *Suggested tasks during contingency ultrasound operations*

- Identifies indications for an imaging study as part of clinical evaluation.
- Obtains permission to invoke resources necessary to activate the Ultrasound System.
- Orders imaging study(-ies), generally per the List of Applications (Appendix 1); this initiates activation of the ISS Ultrasound System.
- Establishes priority and preferred timing of the imaging session relative to other medical activities and decisions.
- Communicates with the remote guidance expert(s) to
  - share expectations from the imaging study and the current differential diagnosis.
  - develop a diagnostic support plan and prioritize clinical questions.
  - optimize the imaging sequence and maximize the effectiveness of the study.
  - provide history and other relevant information.
  - confirm the selection of probes for deployment.
  - confirm constraining and safety requirements.
- Communicates with the subject of the ordered imaging study.
- Communicates with the ultrasound operator on board to provide the purpose, goals, and significance of the study, patient and operator restraints, "GO" to power up the Ultrasound System, selection of probes, and directions to any notes/instructions/illustrations sent electronically.
- Receives preliminary information during the study and modifies the scope of the study.
- Receives the final imaging report.
- Makes decisions regarding follow-up studies as clinically indicated, and communicates decisions to flight director, BMFC, HRF, remote guidance expert, and imaging physician.

6.1.2. *Recommended relevant training*

- ISS Contingency Ultrasound Class
- Principles of Remote Guidance Class

6.1.3. *Recommended relevant experience*

- No specific imaging data acquisition or interpretation experience required.

6.1.4. *Relevant information resources*

- The current version of this publication complete with all appendices.
- HRF ultrasound activation/deactivation procedures.
- ISS medical checklist.
- HRF Ultrasound Activation and Use for Medical Contingencies (a section in the Flight Controller's Operations Handbook – an internal NASA document).
- Patient medical documentation and relevant preflight imaging data if available.

6.2. Biomedical Flight Controller (if imaging is for medical purposes[6])

Two ISS BMFCs are required for effective activation and support of the ISS Ultrasound Imaging System.

6.2.1. *Tasks during contingency ultrasound operations*

- Receives order for an imaging study from crew surgeon.
- Calls TSC operations to request contingency (clinical) ultrasound imaging support.
- Communicates with other console positions to coordinate timing and support of the ultrasound study (Operations Plan, GC, Communication and Tracking Officer).
- Provides procedures for hardware configuration to flight director.
- Confirms all space and ground components of the ISS Ultrasound System with the remote guidance expert, including reference tools, headsets, accessories, and hardware modes/settings.
- Communicates with the flight director and HRF systems regarding rack commanding.
- Coordinates private voice with Houston voice and video with GC.
- Confirms display of restricted video at the Biomed MPSR and private audio loop(s), readiness of data recording capability.
- Reports "All ready for remote guidance" to the crew surgeon, once all steps in the respective Flight Controller's Operations Handbook (FCOH) procedure are completed.
- Provides communication availability/outage information to the flight surgeon and remote guidance expert during the imaging session.
- Monitors data acquisition process (number of still images or cine loops captured), and coordinates post-study data downlink with HRF systems.
- Supports data storage, duplication, review, and archival as appropriate.

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[6] Some of these functions, which are essential for imaging for research purposes, can be accomplished by an appropriately trained HRF personnel, if available

6.2.2. *Reecommended relevant training*

- ISS Contingency Ultrasound Class
- BMFC or CHeCS console certification
- Principles of Remote Guidance Class

6.2.3. *Recommended relevant experience*

- No specific imaging data acquisition or interpretation experience required.

6.2.4. *Recommended information resources*

- HRF Ultrasound Activation and Use for Medical Contingencies (a section in the FCOH – an internal NASA document)
- ISS Operations Audio and Video Configurations (a section in the FCOH – an internal NASA document)
- ISS Medical Checklist (an on-board information resource available in both English and Russian, in paper and electronic formats)
- Medical Operations Console Handbook (an internal NASA document)

6.3. Remote Guidance Expert (if imaging is for medical purposes[7])

6.3.1. *Tasks during clinical ultrasound operations*

- Receives directions regarding the clinical aspects of ISS contingency ultrasound imaging from flight surgeon.
- Receives directions regarding the engineering, technical, and logistical aspects of ISS contingency ultrasound imaging from the BMFC.
- Conducts remotely guided ultrasound examination per the crew surgeon's order, scope, differential diagnosis, prioritized clinical questions, and other information received from the crew surgeon.
- Provides preliminary information on the quality, completeness, and overall success of the study in terms of meeting its objectives, and answers specific questions during the course of the remotely guided study to the crew surgeon.
- Receives crew surgeon and imaging physician input to modify the course and/or scope of the study, based on the preliminary information.
- Suggests preliminary interpretation to the flight surgeon, pending data review by the imaging physician. In some circumstances, the flight surgeon may also be qualified to serve as the imaging physician.

6.3.2. *Recommended relevant training*

- ISS Flight Surgeon Contingency Ultrasound Class
- Principles of Remote Guidance Class

[7] Some of these functions, which are essential for imaging for research purposes, can be accomplished by an appropriately trained HRF personnel, if available

6.3.3. *Recommended relevant experience*

- Fully self-sufficient hands-on experience of ultrasound imaging in a respective area (currently classified as echocardiography, vascular technology, general/abdominal, musculoskeletal).
- Familiarity with the ISS ultrasound hardware or its commercial precursor (HDI-5000, Advanced Technology Laboratories (ATL)/Phillips).
- Remote guidance practice with the use of the ultrasound reference image in a simulated environment with a time delay and inexperienced operator..

6.3.4. *Relevant information resources available to the remote guidance expert*

- The current revision of this document complete with all appendices.
- Ultrasound reference image.
- Access to relevant patient history information as determined by crew surgeon.
- Access to relevant preflight imaging information.

6.4. Remote Guidance Expert: Research Protocol

6.4.1. *Tasks during research ultrasound operations*

- Receives directions regarding the scientific goals to address with ultrasound imaging from the Principal Investigator.
- Receives directions regarding the engineering, technical, and logistical aspects of ISS ultrasound imaging from HRF personnel.
- Conducts remotely guided ultrasound examination per the Principal Investigators' science proposal, scope, and prioritized scientific objectives.
- Provides preliminary information on the quality, completeness, and overall success of the study in terms of meeting its objectives.
- Receives investigator input to modify the course and/or scope of the study, based on the preliminary information.

6.4.2. *Recommended relevant training*

- Principles of Remote Guidance Class

6.4.3. *Recommended relevant experience*

- Fully self-sufficient hands-on experience of ultrasound imaging in a respective area (currently classified as echocardiography, vascular technology, general/abdominal, musculoskeletal).
- Familiarity with ISS ultrasound hardware or its commercial precursor (HDI-5000, ATL/Phillips).
- Remote guidance practice with the use of ultrasound reference image in a simulated environment with a time delay and inexperienced operator.[8]

[8]The currently available facilities to support this requirement are the PDL at JSC and the Medical Simulation Laboratory (MSL) at Wyle Laboratories, Life Sciences Group.

6.4.4. *Relevant information resources*

- The current version of this document complete with all appendices.
- Ultrasound reference images.
- Access to relevant history of the subject as determined by crew surgeon.
- Access to relevant preflight imaging information as determined by crew surgeon.

6.5. Imaging Physician or Investigator[9]

6.5.1. *Tasks during ultrasound operations*

- Provides input to flight surgeon and remote guidance expert to modify course and/or scope of the study, based on the preliminary and real-time information.
- Interprets the imaging results and generates the final imaging report.
- Provides recommendations regarding further follow-up.

6.5.2. *Recommended relevant training*

- Board-Certified Physician (U.S.) qualified and possessing required credentials to interpret ultrasound imaging data. Generally, a radiologist with regular involvement in ultrasound imaging.
- ISS Flight Surgeon Contingency Ultrasound Class.
- Principles of Remote Guidance Class.

6.5.3. *Recommended relevant experience*

- Familiarity with remote guidance methodology, capabilities, and limitations.
- Basic familiarity with microgravity/space physiology.

6.5.4. *Relevant information resources*

- The current version of this document complete with all appendices.
- Access to relevant patient/subject history information as determined by crew surgeon.
- Access to relevant preflight imaging information as determined by crew surgeon.

6.6. Telescience Center Operations Personnel

6.6.1. *Tasks during contingency ultrasound operations*

- TSC operations console positions support payload and TSC operations.
- For a medically indicated examination, TSC operations are contacted by the BMFC to initiate HRF support for contingency ultrasound operations.
- TSC operations contact HRF systems, operations, and hardware personnel and request that they report to the TSC.

[9] Note: This may be the same person as the remote guidance expert.

6.6.2. *Recommended relevant training*

- HRF Contingency Ultrasound Class: TBD class conducted by HRF training personnel.

6.6.3. *Recommended relevant experience*

- Certification as a TSC operations console operator.

6.6.4. *Relevant information resources*

- HRF Ultrasound Activation and Use for Medical Contingencies (a section in FCOH – an internal NASA document).
- Payload Operations Handbook (POH): (an internal NASA document).

6.7. Human Research Facility Systems Engineer

6.7.1. *Tasks during ultrasound operations*

- Commands configuration of HRF rack.
- Monitors health and status of HRF rack and equipment (ultrasound, laptop, rack).
- Coordinates downlink of all images captured from ultrasound.
- Commands HRF rack shutdown at completion of ultrasound session.
- Coordinates all above activities through the BMFC (medical) or HRF (science).
- Informs MSFC of rack activity.

6.7.2. *Recommended relevant training*

- HRF Contingency Ultrasound Class

6.7.3. *Recommended relevant experience for this position*

- Certification as a payload support engineer.

6.7.4. *Relevant information resources available to this position*

- HRF Ultrasound Activation and Use for Medical Contingencies (a section in an internal NASA document)
- POH (an internal NASA document)
- Current version of this publication

6.8. Human Research Facility Hardware/Experiment Science Support

6.8.1. *Human Research Facility personnel tasks during contingency ultrasound operations*

- If necessary, the ultrasound hardware engineer will be called to the Biomed MPSR during contingency ultrasound operations to monitor hardware and troubleshoot any anomalies.
- If necessary, the ultrasound experiment support scientist (ESS) will be called to the TSC during contingency operations. The ultrasound ESS is the most familiar with all operations associated with ultrasound procedures and is the point of contact between HRF and Medical Operations regarding ultrasound procedures.

6.9. Telescience Center Data Systems Group

The TSC Data Systems Group is responsible for processing the data that come down from the ultrasound equipment through payload commanding. The Data Systems Group provides the data on removable media to TSC operations to deliver to the BMFC or the Principal Investigator. Personnel assigned to the Data Systems Group should be at their consoles in the TSC when the data are downlinked and should be prepared to process the data immediately following receipt. The processing time will depend upon the amount of data downlinked.

7. Crew Knowledge, Skill Sets, and Training

The use of remote guidance protocols eliminates the need for the crew to acquire and retain knowledge of specific imaging applications, target views and images, or scanning sequences and protocols. However, the crew must be familiarized with certain aspects identified in table 3, which was composed for purposes of preparedness for a potential contingency (medical) imaging session. The same basic knowledge and experience would allow conducting an out-of-schedule research activity. However, preflight training needs for scheduled research activities may be considered experiment-specific, hence may substantially differ from the training approach taken for the operational activity (figure 2).

Table 3. Components of Training for a Potential Operator in Remotely Guided Ultrasound Imaging

No	Component	Org.	Time
1	HRF rack operations, HRF Ultrasound hardware and its components, configuration, and operation (Standard HRF rack and ultrasound training conducted in Payload training flow)	HRF	120 min
2	The components, setup, and activation sequence of the ISS Ultrasound System	Med Ops	30 min
3	Physical principles of ultrasound imaging and its clinical utility	Med Ops	
4	General imaging procedure including the use of gel, probe manipulation, microgravity factors, positioning and restraints, other relevant human factors	Med Ops	
5	The principles of remote guidance, including associated items, activities, and procedures such as the use of VOX communication system	Med Ops	
6	Practice as a remotely guided ultrasound operator (laboratory setting, human subject)	Med Ops	30 min

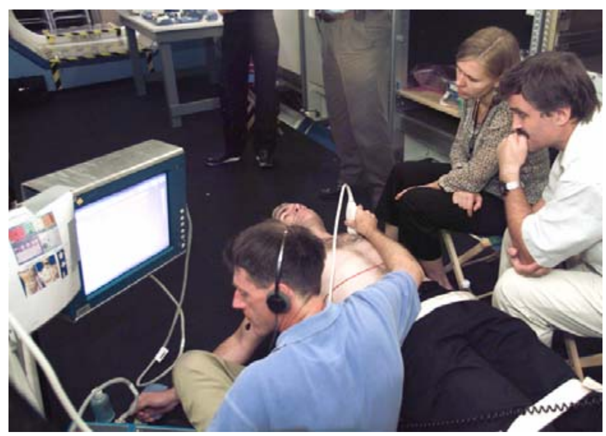

Figure 2. *Above:* Expedition Commander Michael Foale (ISS Increment 8) during his scanning practice session in the Payload Development Laboratory at JSC. *Below:* Dr. A. Sargsyan (Wyle Laboratories) is conducting a demonstration of the scanning technique for the Expedition 12 crew (W. McArthur, V. Tokarev).

As shown in table 3, specific training components for contingency ultrasound can be limited to one hour per crew member. This suggested ultrasound training requirement was satisfied for Expeditions 8 through 11 (and back-up crews), through the ADUM experiment training (figure 3). No ultrasound training is currently included in the CMO curriculum.

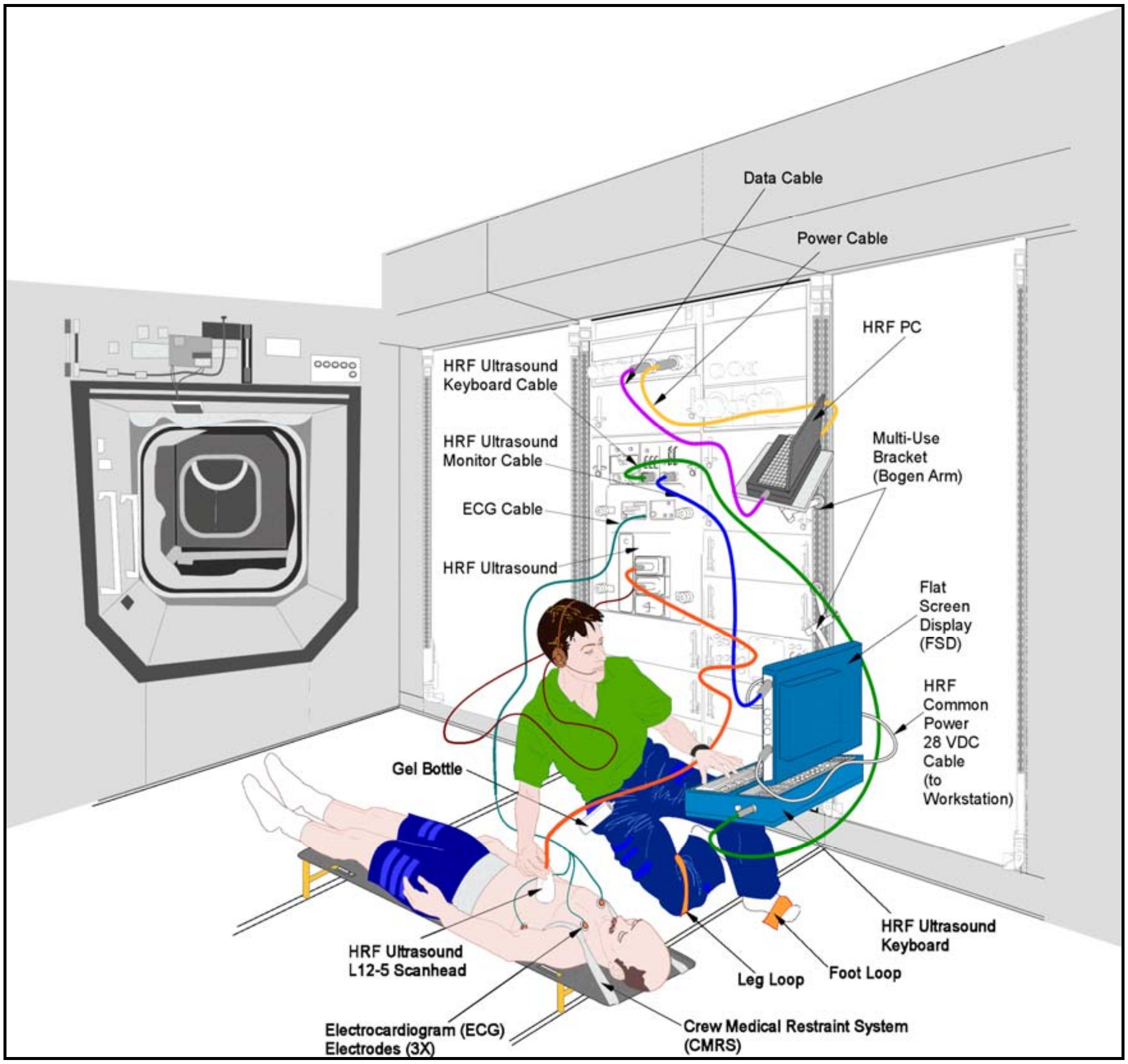

Figure 3. Hardware configuration for ultrasound operations. Note: Operator is restrained in a position that ensures easy access to both the patient (right) and the keyboard (left) while viewing the flat screen (FS).

Each crew receives hardware training on rack operations and ultrasound hardware configuration by HRF personnel, per the principle of shared resources (table 3, row 1). No knowledge retention practice or performance testing is provided presently or anticipated in the near future.

8. Ultrasound Applications Available for Ordering

Medical literature published by authors and other researchers, results of NASA developments and experiments, and expert consultations have been used in identifying and prioritizing medical conditions where ultrasound data are expected to substantially influence patient management on orbit. Implementation of operational ultrasound imaging for these medical conditions, in addition to the general microgravity imaging procedures, also requires application-specific protocols and techniques. Development of these protocols for the International Space Station (ISS) began in 1999, and generally has followed a four-phased approach. It is not always necessary or practical to conduct Phases II and III, and assumptions may be made to transition directly from Phase I to Phase IV. The four phases are as follows:

I. Identification of a proven terrestrial technique/application used on humans, or recognition of a potential technique

II. Validation of technique/application on a model in one g (human or animal)

III. Validation of technique/application on a model in a simulated microgravity environment (human or animal)

IV. Operational implementation of technique for use on humans in microgravity (ISS)

Such structured development and validation focuses on procedure, remote guidance techniques and terminology, scanning protocols, data consistency, and identification of microgravity-induced factors. The latter includes changes in normal anatomy and physiology, such as the redistribution of liquid, gas, and tissue, changes in blood flow and vascular patterns, and ergonomic challenges such as mutual positioning or operator fatigue. Multiple specific questions are answered partially or entirely with each ultrasound imaging session on the ground, in simulated microgravity, and on orbit. The imaging sessions conducted to date have resulted in a library of microgravity-adapted procedural components, focused scanning protocols and sequences, and “plug-in” modules to complement the standard techniques for ultrasound imaging.

Feasible ultrasound applications categorized as Complete (Standard), Focused and Limited, and Image-Guided Manipulations are listed in Appendix 1. The first two groups of noninvasive imaging applications are available to surgeons on console for ordering.

Applications classified as “Image-guided manipulations” are invasive procedures that have never been attempted in humans by remote guidance or in microgravity conditions. The limited experience acquired on animal models suggests the general feasibility of image-guided needle (i.e., instrument) introduction on ISS, but with an undefined risk of failure and/or iatrogenic complications. The probability of failure or complications would certainly depend on the particular application and circumstances surrounding the clinical case. Should such an interventional procedure be suggested for an ISS crew member, a clinically active interventional radiologist or another specialist with appropriate expertise would be required. The risk *vs.* benefit considerations must include a thorough ultrasound survey of the area, the efficacy of remote interaction with the CMO, and time and communications factors (including availability of simultaneous cabin view camera video).

9. Hardware Configurations

9.1. Human Research Facility Ultrasound Configuration

The HRF Ultrasound System is an HDI-5000 (ATL/Philips, Bothell, Wash.) system that has been repackaged and modified to meet the power, cooling, and fire suppression requirements for a closed microgravity environment. This is a multipurpose ultrasound imaging system that is widely used for terrestrial clinical care and medical research. The on-board system is equipped with the three most broadly used probes, which are considered essential to cover a majority of foreseeable imaging applications in adults, including all applications listed in Appendix 1. Each probe features a set of advantages and limitations. None of the available probes individually covers the entire range of space medicine applications.

The HDI-5000 configuration for a given space medicine application includes

- Unstowing and connecting the ultrasound monitor and keyboard (MGUEHRFADUMR001 – cabling diagram used for ADUM experiment).
- Unstowing the HRF personal computer laptop and activating image collection software to allow collected images to be downlinked following the scan (unstowing typically not required because the HRF laptop is nominally deployed).
- Unstowing and connecting one or more probe(s).
- Unstowing and connecting the ECG cable, if needed.
- Locating the CMRS near the HRF rack and ultrasound, if needed.
- Selecting a pre-connected probe for initialization.
- Selecting a factory-programmed or custom "tissue preset" from the "transducer" menu of the system.
- Initiating a new patient data record on the system hard drive by entering an alphanumeric patient ID in the "patient data" menu of the system.
- Making further adjustments of system parameters as required to acquire the necessary scan(s), typically under real-time guidance by expert.
- Providing support equipment (cue card, VOX, cameras, wipes for probes, electronically uplinked messages/reference cards specific for upcoming scan.)

9.2. Ultrasound Probes

The probes listed in table 4 are considered essential for meeting most foreseeable imaging needs. Other probes, currently unavailable aboard ISS, could be advantageous in specific situations and would provide desirable redundancy; however, financial and up-mass considerations have prevented their deployment on ISS at this time.

Table 4. HDI-5000 Probe Applications by Anatomical Regions

No.	Design.	Type	Application	Backup
1	C5-2	Curved Array (convex)	Abdominal / pelvic (primary) Vascular – deep vessels (alternative) Cardiac – limited (alternative)	P4-2
2	L12-5	Linear Array	Superficial organs and tissues (primary) Musculoskeletal (primary) Chest wall/pneumothorax (primary) Peripheral vascular (primary) Ophthalmic (primary) Dental/facial (primary)	C5-2 (limited)
3	P4-2	Phased Array (electronic sector)	Cardiac (primary) Abdominal/pelvic (alternative)	C5-2 (limited)

9.2.1. *C5-2 curved array probe10*

This broadband curved array probe is the primary choice for all abdominal or pelvic sonography applications. The probe acquires fan-shaped images at depths up to 22 cm through a relatively large window. If this probe is unavailable, the P4-2 phased array probe is selected as a lower-resolution alternative acceptable for most respective applications. In certain situations, the P4-2 may be chosen as the primary probe; these include unsatisfactory imaging conditions when deeper penetration and (or) a very small imaging aperture are desired.

9.2.2. *L 12-5 (38mm) linear array probe*

The L12-5 linear array probe resolves superficial tissue with clarity, provides high tissue contrast, and spatial resolution. This high-frequency broadband probe acquires rectangular-shaped images to a maximum depth of 7 cm.

This is the only probe that is capable of resolving very superficial anatomical structures. Organs and issues subject to scanning with this probe include superficial soft tissues, eyes, thyroid gland, salivary glands, breast, and male gonads. This probe is also used for the detection or exclusion of pneumothorax by visualizing the chest-to-lung interface. L12-5 provides fine detail of muscles, fascia, tendons, ligaments and joints, as well as superficially positioned bones. For example, such use may be indicated if a muscle tear, a tendon rupture, or a rib fracture is suspected.

9.2.3. *P4-2 phased-array probe*

This phased-array probe has a very small footprint (face), hence its primary role is cardiac imaging. Through a narrow aperture (window) between ribs, it allows acquiring sector-shaped images with a field of view up to 22 cm in depth. This probe is also a backup, lower-resolution alternative for C5-2 for most abdominal and pelvic applications. However, it may be used as a primary probe for abdominal imaging in a large subject, or under imaging conditions where deeper penetration and small aperture are necessary.

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[10]Technical information, such as specifications of this and other HRF hardware, is available from the personnel supporting the ISS HRF facility.

10. On-orbit Human Factors

10.1. Subject Examination by Operator vs. Subject Self-examination

In case of serious illness or injury, a patient is assumed incapacitated and unable to assist the operator (caregiver). Patient examination by operator is therefore considered the primary mode of contingency ultrasound. In this mode, the patient is restrained by the CMRS in the majority of applications. A dedicated operator is necessary if the patient (or research subject) is required to be restrained on the CMRS.

Self-examination is a possible alternative only in a limited set of applications. It also limits examination to certain areas of the body and to a limited set of body positions. However, if mission circumstances render involvement of the second crew member unsafe or impossible, self-examination may be the only choice. Decisions in such circumstances would be made on a case-by-case basis.

10.2. Patient and Operator Positioning and Restraints

Positioning of both the patient and the operator is an important determinant of the quality of an imaging study. The restraining techniques are coordinated with the investigators or the flight surgeon. Nominally, the CMRS is installed in position LAB1D5/D6. An appropriate combination of straps provided with the CMRS is used to restrain the patient and, potentially, the operator. The choice of straps depends on the anatomical area of probe application, as well as other medical monitoring and treatment considerations. Both shoulder straps and the belt strap are used by default. The longitudinal (midline) strap is not applied as it interferes with probe application in most cases.

Stability of the probe position, controlled pressure, and steady, purposeful movement of the probe are also important factors for image quality and success of remote guidance. A successful study (examination) can be initiated and maintained throughout the session only with the convenient, stable position of the operator. Foot restraints, CMRS CMO straps, and the space under the CMRS are nominally used to restrain the operator and free both hands for probe and keyboard manipulation.

The flat screen display (FSD) must be viewed at an angle close to 90 degrees. The ultrasound keyboard must be within easy reach of the operator's hand. Reaching the keyboard must not interrupt the imaging process, or result in a change in probe position or pressure on the probe.

If the subject is capable, (s)he can assist the operator with keyboard strokes/manipulations, thus allowing the operator to concentrate on image acquisition during the scan. VOX should be on speaker to allow both crew members access to audio. In a number of applications, the imaging expert must communicate directly with the patient (e.g., giving commands such as "hold your breath," "bear down," etc.).

Default positions of the crew members, ultrasound peripherals, and accessory items are shown in figure 3.

10.3. Placement and Use of Reference Materials

The Ultrasound Reference Image (Appendix 4) can be seen as an essential component of the ISS Ultrasound Imaging System. It should be attached to the frame of the HRF FSD. The application-specific reference images (Appendix 5), if provided by the Investigator or Remote Guidance Expert, are also positioned within the field of view of the operator. Hard copies of the "Cue Card" are located in the HRF rack (with the probes) and in the medical checklist (an on-board information resource available in both English and Russian, in paper and electronic formats). In addition, there is an electronic copy in the ISS manual procedures viewer.

11. Supporting Evidence and Summary of Events

As explained in section 4, imaging applications in a medical contingency may not be fully supported by knowledge and formal evidence, or may differ in their nature and from that commonly expected for mainstream terrestrial imaging procedures. Therefore, in each case and as possible, the imaging report must be supplemented with additional information regarding existing relevant knowledge and precedents as of the time of the examination.

As of September 2006, multiple evaluations of remotely guided ultrasound imaging applications have been conducted on orbit (Expeditions 5, 6, 7, 8, 9, 10, and 11) by JSC Space Medicine Division and/or the HRF/ADUM experiment. Highlights of these events are provided in Appendix 7, which will be updated in future versions of this publication. ADUM session events and accomplishments will be described upon completion of the experiment report.

12. Expected Forward Work

- Efforts will be made to update the online version of this publication as relevant changes or new developments occur.
- Training and familiarization mechanisms will be developed for transferring applicable knowledge and expertise from the JSC Space Medicine Division and Wyle Laboratories personnel to the potential users as such demands arise and circumstances permit.
- Additional board-certified radiologists with enhanced ultrasound experience will be sought to act as ultrasound consultants in case of a medical contingency aboard ISS.
- ADUM experiment results (including the ADUM final report) are expected to be completed, and recommendations contained in the ADUM final report will be considered for use to upgrade this text, to plan further studies, or for other relevant purposes.
- Microgravity imaging/remote guidance techniques should be developed or refined for ultrasound applications that are currently deemed feasible but have not been demonstrated by Space Medicine or ADUM experiment.
- Evidence should continue to be collected for conditions under which ultrasound may be applicable.
- Documentation related to contingency ultrasound imaging must be kept in continued compliance with the HRF procedures.

13. Appendices

13.1. Appendix 1: Recommended Ultrasound Applications

The majority of the following applications have been tested or demonstrated in the context of remote guidance and/or microgravity. Some applications are included that have not been tested but are considered feasible due to their similarity with other tested applications.

Note: Image-guided manipulations are interventional (minimally invasive) therapeutic and/or diagnostic procedures in which ultrasound plays an accessory/supporting role. The risk of failure or iatrogenic complications of these procedures under remote guidance has not been evaluated. Also see text in section 8.

I. HEAD, NECK, AND FACE [11]

Application Title	Type	Notes/Scope	Performed w/ remote guidance?	Performed on ISS?
Ophthalmic Sonography	Complete (Standard)	B-mode sonography of the globe and orbital structures. Axial distance measurements (similar to A-mode) of the globe/ media are possible (correction factors may be necessary).	Y	Y
Salivary Gland Sonography Complete	Complete (Standard)	Diagnostic or as enhancement to thyroid sonography.	D	N
Thyroid Sonography Complete	Complete (Standard)	Standard clinical or research protocols.	Y	Y
Carotid Duplex Sonography Complete	Complete (Standard)	Standard or specialized protocols with Doppler measurements of flow velocities in CCA, ICA, ECA, and VA.	D	D
Paranasal Sinus Sonography	Focused and Limited Studies	If clinically indicated to confirm suspected maxillary or frontal sinusitis. Accuracy in microgravity is not established.	Y	Y
Dental/Oral Sonography	Focused and Limited Studies	Extraoral approach only, if clinically indicated to confirm suspected periapical abscess.	Y	Y
Salivary Gland Sonography	Focused and Limited Studies	Involves comparative imaging of contralateral gland and the thyroid.	Y	N
Ophthalmic Sonography – Limited	Focused and Limited Studies	Unilateral or F/U study (clinical); precise distance measurements (such as A-P diameter or retinal thickness) may require adjustment coefficients etc.).	Y	Y
Ophthalmic Sonography – PLR	Focused and Limited Studies	Pupillary light reflex.	Y	D
Jugular Vein Sonography Specific	Focused and Limited Studies	Scope must be specified and protocols validated in ground tests.	Y	D
Image-Guided Vascular Access (Internal Jugular Vein)	Image-Guided Manipulations	See section 8.	N	N
Ultrasound pupillometry	Focused and Limited	Experimental technique with visualization of the iris and recording of diameter and temporal parameters with high temporal and spatial resolution.		

[11] **Y:** The application was successfully performed in full with remote guidance; **D:** the application was performed with remote guidance partially or to the extent sufficient to demonstrate feasibility; **A:** the application was performed on animal model (s); **NA:** not applicable; **N:** the application has not been performed in the given setting.

II. Heart

Application Title	Type	Notes/Scope	Performed w/ remote guidance?	Performed on ISS?
Echocardiography, Complete	Complete (Standard) Studies	Pericardial space, valves, chambers/walls, wall motion, color and spectral Doppler in standard locations, standard cardiac calcs). Thoracic windows may change in microgravity. Preflight baseline (supine and supine head-down tilt) is recommended to assess degree of difficulty of future in-flight tests.	Y	Y
Stress-Echocardiography, Complete	Complete (Standard) Studies	Concurrent CEVIS use is required. Possible in the current (LAB module) location of the HRF rack.	Y	D
Echocardiography, Pericardial Space	Focused and Limited Studies		Y	Y
Echocardiography, Valve(s)	Focused and Limited Studies		Y	Y
Echocardiography, Chamber/Wall	Focused and Limited Studies		Y	Y
Echocardiography, Wall Motion	Focused and Limited Studies		Y	Y
Echocardiography, Limited	Focused and Limited Studies	Full-up or limited study (medical) or specific research protocol.	Y	Y
Pericardiocentesis, by Ultrasonic Guidance	Image-Guided Manipulations	See section 8.	N	N

III. Thorax

Breast Sonography Complete Bilateral	Complete (Standard) Studies	Standard “terrestrial” protocol(s)	N	N
Pleural Space Sonography Complete Bilateral	Complete (Standard) Studies	Bilateral, rule out or describe pleural effusion, hemo-, pneumothorax.	Y	Y
Shoulder Sonography Complete Bilateral	Complete (Standard) Studies	Rotator cuff, joint, adjacent soft tissues.	Y	Y
Sonography for Pleural Effusion	Focused and Limited Studies		Y	Y
Diaphragm Sonography	Focused and Limited Studies		Y	D

Sonography for Trauma / Subcutaneous Emphysema	Focused and Limited Studies	Scope must be specified.	D	D
Pleural Space Sonography Ltd	Focused and Limited Studies	Involves multiple thoracic locations (primary diagnostic purpose) or a limited set of locations (follow-up).	Y	Y
Thoracentesis, by Ultrasonic Guidance	Image-Guided Manipulations	See section 8.	A	N
Thoracostomy (Chest Tube Placement) by Ultrasound Guidance	Image-Guided Manipulations	See section 8.	A	N
Image-Guided Vascular Access	Image-Guided Manipulations	Subclavian vein. See section 8.	N	N
Other	Image-Guided Manipulations	See under "Any Location."	NA	NA

IV. ABDOMEN AND RETROPERITONEUM

Application Title	**Type**	**Notes/Scope**	**Performed w/ remote guidance?**	**Performed on ISS?**
Abdominal Sonography Complete	Complete (Standard)	Complete survey incl. liver, biliary system, pancreas, spleen, kidneys, AA, IVC, peritoneal space.	Y	Y
Renal Sonography Complete	Complete (Standard)	Includes limited Doppler evaluation, urinary bladder, "ureteral jets."	Y	Y
Renal Arterial Duplex Sonography Complete	Complete (Standard)	Standard "terrestrial" protocol includes visualization plus Doppler spectra from AA and three locations or RA bilaterally.	Y	D
Adrenal Gland Sonography	Complete (Standard)	Bilateral.	Y	D
Abdominal Aorta Duplex Sonography Complete	Complete (Standard)		Y	D
Scrotal Sonography Complete	Complete (Standard)	Standard terrestrial protocol, including color Doppler imaging.	N	N
Prostate Sonographic Survey	Complete (Standard)	Trans-vesical (abdominal) approach. Requires a full bladder.	Y	Y
Prostate and Urethra Sonography High-Resolution	Complete (Standard)	External (perineal approach).	N	N
Hepatic Sonography	Focused and Limited	Scope must be specified.	Y	Y
Hepatic Sonography with Vascular Evaluation	Focused and Limited	Portal vein sonography for medical purposes (visualization, color Doppler, spectral Doppler). Research protocols must be validated in remote guidance setting in controlled laboratory conditions.		
Portal System Duplex Sonography	Focused and Limited	Includes PV, SMV, IMV, SV, with Doppler flow demonstrations and measurements per specific protocols.	D	D
Gallbladder Sonography	Focused and Limited	Includes biliary system (intrahepatic and extrahepatic ducts).	Y	Y

Application Title	**Type**	**Notes/Scope**	**Performed w/ remote guidance?**	**Performed on ISS?**
Pancreas Sonography	Focused and Limited		Y	Y
Spleen Sonography	Focused and Limited		Y	Y
Renal Sonography Specific	Focused and Limited	For example, Unilateral, F/U.	Y	Y
Urinary Tract Obstruction – Sonography Localization	Focused and Limited	Identification of level and nature of obstruction; includes bilateral Doppler study of ureteral orifices.	A	D
FAST Examination	Focused and Limited	Includes peritoneal, pericardial potential spaces.	Y	Y
FAST Examination Expanded	Focused and Limited	Includes peritoneal, pericardial and both thoracic potential spaces.	Y	Y
Peritoneal Space	Focused and Limited	Specify purpose, e.g. suspected effusion or F/U to FAST exam.	Y	Y
Appendicitis (appendix) Sonography	Focused and Limited Studies	RLQ sonography with graded compression.	D	D
GI Tract Sonography	Focused and Limited	Evaluates peristalsis, small bowel diameter, estimates content in terms of liquid / gas (fluid sequestration). Specific scope can be set for specific suspected conditions, levels of obstruction, and other clinical questions. Peristalsis can be described and monitored.	D	D
Other Abdominal Vascular Duplex Sonography	Focused and Limited	Scope must be specified. Research protocols must be pre-validated in controlled laboratory conditions.	D	D
Urinary bladder Sonography – Female	Focused and Limited	Bladder volume, presence of debris or clots, urethral angle, other signs per the specified scope.	Y	Y
Urinary Bladder Sonography – Male	Focused and Limited	Bladder volume, presence of debris or clots, other signs per the specified scope.	Y	Y
Abdominal Sonography, Limited	Focused and Limited	F/U, or limited study – scope must be specified.	Y	Y
Laparocentesis, by Ultrasonic Guidance	Image-Guided Manipulations	See section 8.	A	N
Image-Guided Aspiration, Drainage, Injection, or Infusion – Intraabdominal	Image-Guided Manipulations	See section 8.	A	N
Other	Image-Guided Manipulations	See under "Any Location."	NA	NA

V. Gynecology And Pelvis

Application Title	Code	Notes/Scope	Performed w/ remote guidance?	Performed on ISS?
Female Pelvic Sonography, Complete	Complete (Standard)	External (abdominal approach). Requires full bladder. Includes evaluation of the uterus, adnexae, and potential abdominal/pelvic space per the standard "terrestrial" protocol. No endocavity probe is available.	D	D
Female Pelvic Sonography, Limited/Specific	Focused and Limited	For example, known or suspected uterine /pelvic mass, PID, F/U study (abdominal approach). No endocavity probe is available.	D	D
Female Pelvic Sonography, Endometrial Evaluation	Focused and Limited	Scope must be specified.	Y	D
Other Female Pelvic Sonography	Focused and Limited	Scope must be specified.	D	NA
Image-Guided Manipulations	Image-Guided Manipulations	NA	NA	NA

Table VI. Extremities And Peripheral Vasculature

Arterial Duplex Sonography, Upper Extremity, Complete	Complete (Standard)	Specify side or bilateral.	N	N
Venous Duplex Sonography, Upper Extremity, Complete	Complete (Standard)	Specify side or bilateral. Standard "terrestrial" protocol with compression.	N	N
Arterial Duplex Sonography, Lower Extremity, Complete	Complete (Standard)	Specify side or bilateral.	Y	D
Venous Duplex Sonography, Lower Extremity, Complete	Complete (Standard)	Specify side or bilateral. Standard "terrestrial" protocol with compression.	Y	D
Musculoskeletal Sonography	Complete (Standard)	See under "Any Location."	NA	NA
Arterial Duplex Sonography, Lower Extremity, Limited	Focused and Limited	Specify side or Bilateral. Scope must be specified. Research protocols must be validated in remote guidance setting in controlled laboratory conditions.	Y	D
Venous Duplex Sonography, Lower Extremity, Limited	Focused and Limited	Specify side or Bilateral. Research protocols must be validated in remote guidance setting in controlled laboratory conditions.	Y	D
Musculoskeletal Sonography	Focused and Limited	See under "Any Location." Research protocols must be validated in remote guidance setting in controlled laboratory conditions.	NA	NA
Other	Image-Guided Manipulations	See under "Any Location."	NA	NA

VII. Any Location (Extracavitary) and Miscellaneous

Application Title	Type	Notes/Scope	Performed w/ remote guidance?	Performed on ISS?
Soft Tissue Trauma Sonography	Focused and Limited	Specify.	D	D
Soft Tissue Mass Sonography	Focused and Limited	Specify.	D	N
Soft Tissue Infection Sonography	Focused and Limited	Specify.	N	N
Foreign Body Localization Sonography	Focused and Limited	Specify.	N	N
Sonography for Bone Trauma / Fracture	Focused and Limited	Specify .	Y	D
Sonography for Bone Fracture F/U	Focused and Limited	Specify.	D	D
Articular Sonography	Focused and Limited	Specify.	Y	D
Other Musculoskeletal Sonography	Focused and Limited	Tendon, ligament, bursa – specify.	Y	D
Regional Lymph Node Sonography	Focused and Limited	Specify .	Y	D
Other Focused or Limited Soft Tissue Sonography	Focused and Limited	Specify.	NA	NA
Image-Guided Fluid Aspiration – Diagnostic	Image-Guided Manipulations[12]	Specify. See section 8.	A	N
Image-Guided Fluid Aspiration – Therapeutic	Image-Guided Manipulations	Specify. See section 8.	A	N
Image-guided Injection/Infusion	Image-Guided Manipulations	Specify. See section 8.	A	N
Image-Guided Conductive Anesthesia – Peripheral nerves	Image-Guided Manipulations	Specify. See section 8.	N	N
Foreign Body Localization – Needle, Soft Tissue	Image-Guided Manipulations	Specify. See section 8.	N	N
Peripheral Vascular Access by Sonography Guidance	Image-Guided Manipulations	Specify. See section 8.	D	N
Other Image-Guided Manipulation	Image-Guided Manipulations	Specify. See section 8.	NA	NA

Y: The application was successfully performed in full with remote guidance; **D:** the application was performed with remote guidance partially or to the extent sufficient to demonstrate feasibility; **A:** the application was performed on animal model (s); **NA:** not applicable; **N:** the application has not been performed in the given setting.

[12] Note: The feasibility of image-guided manipulations under remote guidance has been demonstrated on animal models in an animal lab and KC-135 parabolic flight. Some clinical circumstances potentially requiring these invasive procedures are addressed in our publications (Appendix 9). At this time, these manipulations are not validated for ISS and are not included in the ISS Medical Checklist.

13.2. Appendix 2: Examples of Conditions with Sonographic Signs and Symptoms

No.	Condition Examples	Possible Sonographic Signs/Findings	Terrestrial Use	Alternate Diagnostic Modalities
	Head, Neck, Face			
1	Retinal Detachment	Typical pattern of retinal separation of various degree and topography.	Common in specialized centers	Slit Lamp
2	Retro-vitreal and Intra-vitreal hemorrhage	Typical patterns of irregularly altered echogenicity.	Common in specialized centers	Slit Lamp
3	Lens Displacement (subluxation or dislocation)	Failure to visualize lens in normal position; demonstration of the lens in abnormal position or location.	Common in specialized centers	Slit Lamp, MRI
4	Other Trauma (anterior segment)	Demonstration of hyphema, iris distortion, and other trauma anatomy.	Common in specialized centers	Slit Lamp
5	Sialoadenitis	Hypoechoic gland, enlarged and tender, rounded, possibly dilated ductal system, typical color Doppler signs.	Uncommon	Contrast Sialography, CT
6	Thyroiditis	Relatively hypoechoic gland, possible enlargement (compare to the baseline or adjacent structures - salivary glands and neck muscles), irregular texture; possibly altered color Doppler pattern.	Common	Laboratory tests
7	Periapical Abscess	Translabial/ transbuccal demonstration of a hypoechoic periapical focus.	Uncommon	X-ray, X-Ray tomography, CT, Panorex
	Heart and Thorax			
8	Pericardial Effusion	Demonstration of fluid separation of pericardium.	Common	Gated CT
9	Pneumothorax	Absent sliding of the lung, mirror-image artifact, absent “comet tails.” In severely symptomatic cases, expect same over entire hemithorax, displacement of the mediastinal structures.	Uncommon, but increasingly recognized	CXR, CT
10	Pleural Effusion and Hemothorax	Demonstration of fluid separation between parietal and visceral pleura. Expect wide area of distribution in zero g. Requires follow-up if negative.	Common	CXR, CT
	Abdomen/Retroperitoneum			
11	Acute Appendicitis	Thickened walls of appendix; non-compressibility, increased diameter, increased flow; if complicated - free fluid; localized fluid/ infiltrate, changes in peristalsis. Demonstration of normal appendix allows ruling out appendicitis in most cases. Failure to identify appendix does not rule out appendicitis.	Common and increasing	Non-Contrast CT, Contrast CT, MRI
12	Acute Diverticulitis	Nonspecific findings of focal bowel wall thickening and changes in surrounding fat/tissues; possible identification of the diverticulum, abscess formation, or associated fistula	Known but uncommon	Fluoroscopy, CT, Laparoscopy

No.	Condition Examples	Possible Sonographic Signs/Findings	Terrestrial Use	Alternate Diagnostic Modalities
13	Blunt Abdominal Trauma (includes internal bleeding)	Free fluid at the site of injury; free fluid elsewhere in contiguous peritoneum; organ hematoma; capsular disruption; changes in peristalsis.	Common (FAST) Uncommon (comprehensive)	CT, Laparoscopy
14	Retroperitoneal Hematoma	Detection of hematoma; possible abdominal fluid and/or signs of ileus.	Uncommon, secondary	CT, MRI
15	Inflammatory Bowel Disease	Thickened / infiltrated wall of terminal ileum.	Uncommon	CT, Small Bowel Series, Laparoscopy
16	Hollow viscus perforation (peptic ulcer, trauma)	Pneumoperitoneum; changes in peristalsis, free fluid.	Known but uncommon	CT, Laparoscopy
17	Liver enlargement/Diffuse Process (e.g., toxic)	Changes in shape, lower margin position and shape, dimensions, relative echogenicity, echo-texture.	Common	Laboratory data, CT, Radionuclide (HIDA) Scan
18	Liver or Splenic Hematoma	Focal irregularity; Doppler signs of a space-occupying lesion (SOL).); subcapsular hematomas (typical pattern).	Common	CT
19	Hepatic Abscess	Demonstration of a gradually forming focal irregularity which assumes a round shape; Doppler signs of SOL.	Common	CT
20	Biliary Hypertension due to Obstruction	Dilation of intrahepatic bile ducts and extrahepatic ducts proximal to the cause; possible dilation of the gallbladder; possible dilatation of the pancreatic duct.	Common	CT, ECPG, Endoscopic Ultrasound
21	Abnormal content of the Gallbladder – Sludge, Blood Clots, Calculi, Pneumobilia	Demonstration of irregular echogenicity of gallbladder content; stones readily visualized; data will differ from terrestrial.	Common	CT, HIDA Scan, Endoscopic Ultrasound
22	Acute Cholecystitis (calculous or acalculous)	Thickened/infiltrated walls; possible peritoneal reaction; possible wall irregularity.	Common	CT, HIDA Scan
23	Splenic Enlargement	Changes in shape, relative position, size, relative echogenicity.	Common	CT
24	Splenic Infarct	Wedge-shaped zone of irregularity/low echogenicity.	Common	Contrast CT, Angiography
25	Acute Pancreatitis; Pancreatic Hematoma	Enlargement, low echogenicity; possible irregularity; possible dilation of the duct; possible free fluid and renal changes in severe cases.	Common	CT

Genitourinary/pelvic

26	Renal Calcifications/Calculi	Demonstration of calcifications and/or stones; typical pattern of obstruction if impacted.	Common	IVP, CT
27	Ureteral Obstruction/Renal Colic (stone, blood clot in trauma, urinary reflux)	Demonstration of renal pelvic distention/ureteral dilation proximal to the stone; renal enlargement; possible identification of the cause.	Common	IVP, CT
28	Acute Pyelonephritis and Renal Abscess	Renal enlargement, shape, low relative echogenicity, possible focal lesions/irregularity, possible signs of obstruction; demonstration of abscess (focal lesion of varying echogenicity, irregular contour of the kidney).	Common	Contrast CT, Renal Angiography, Scintigraphy

No.	Condition Examples	Possible Sonographic Signs/Findings	Terrestrial Use	Alternate Diagnostic Modalities
29	Renal Trauma	Zones of irregularity with associated perirenal changes; usually diagnostic in clinical context; Power/Color Doppler essential to evaluate damage and stage/classify.	Common	Contrast CT, Renal Angiography, Scintigraphy
30	Acute Diffuse Pathology, Renal Enlargement (e.g., toxic exposure, ATN)	Renal enlargement, shape, high relative echogenicity, medullo-cortical contrast, change in renal vascular resistivity (pulsed Doppler).	Common	Laboratory Data, CT, Scintigraphy
31	Renal Vein Thrombosis	Changes in size, echogenicity, shape, arterial flow pattern (pulsed Doppler); actual thrombus may be visualized; a complicated and time-consuming procedure.	Common	Contrast CT, Renal Scintigraphy, Angiography
32	Normal Pregnancy (early); Incomplete Abortion Or Blighted Ovum	Demonstration of gestational sac, thickened and echogenic endometrium; typical patterns of complications.	Common	Laboratory data, Endocavity US
33	Ectopic Gestation	Adnexal mass, free pelvic fluid, thickened endometrium; possible demonstration of fetus with or without the heartbeat.	Common	Endocavity US; CT
34	Pelvic Inflammatory Disease (PID)	A variety of sonographic patterns; requires extensive guidance; ectopic gestation must be ruled out.	Common	HCG, CT
35	Bladder Calculi or Blood Clots	Demonstration of a calculus or displaceable irregularly echogenic structure in the bladder lumen; different in zero g *vs*. one g.	Common	Cystoscopy
36	Bladder Infection	Demonstration of turbulent urine in the bladder; thickening of bladder walls; color Doppler interrogation causes "stirring" of turbulence; different in zero g *vs*. one g.	Common	Lab
37	Urinary Retention	Distended bladder, possibly vesico-ureteral reflux with ureteral and renal distention.	Common	CT
38	Acute Prostatitis/Relapse and Prostatic Abscess	Enlarged prostate, irregularity of texture, contour irregularity, possible focal changes, low echo-genicity; "chronic" background changes, e.g., calcifications.	Common	Endocavity (rectal) US
39	Testicular torsion	Critical information from color Doppler; Changes in echo-texture and asymmetry in echogenicity.	Common	Clinical Impression

Superficial

40	Superficial Infections (cellulitis, lymphadenitis, cutaneous abscess, necrotizing cellulitis)	Respective patterns, typical.	Common	Optical Images of Skin; Clinical Impression

Extremities and Peripheral Vasculature

41	Deep Venous Thrombosis (lower extremities)	Lack of vein compressibility, visualization of thrombus, absent or abnormal flow. May be time consuming. Technique may differ in zero g *vs*. one g.	Common	Contrast Venography, MRI, scintigraphy

No.	Condition Examples	Possible Sonographic Signs/Findings	Terrestrial Use	Alternate Diagnostic Modalities
42	Superficial Venous Thrombosis (post-injection, post-catheter)	Lack of compressibility, visualization of thrombus, absent or abnormal flow.	Common	Optical Images of Skin; Clinical Impression
43	Venous Gas Embolism (Decompression)	Demonstration of VGE in B-mode and power Doppler; pulsed Doppler may be used as well (duplex or color-duplex mode)	Uncommon	Pulsed Doppler
44	Superficial bone fractures (rib, mandible, zygomatico-maxillary complex, skull)	Characteristic disruption of cortical bone reflection. Distortion of the bone contour; soft tissue reaction/edema/hematoma.	Common in Specialized Centers	Radiography
45	Long-Bone Fractures	Similar to other fractures; additional techniques (e.g., axial rotation) may enhance study.	Common in Specialized Centers	Radiography
46	Muscle Tears/Hematoma	Hypoechoic zone, irregularity, local enlargement, displacement of adjacent structures.	Common in Specialized Centers	MRI
47	Tendon Rupture	Disruption of the normal pattern, asymmetry, hypoechoic zone; may demonstrate contracted muscle.	Common in Specialized Centers	MRI

13.3. Appendix 3: Remote Guidance Experts with Experience of Remotely Guided Ultrasound on ISS

As of the time of this publication, remotely guided ultrasound aboard the ISS has been supported by the following individuals, who have significantly overlapping expertise in the area.

Dr. Ashot Sargsyan, Space Medicine, Advanced Projects, Wyle Laboratories

- Doctor of Medicine (Internal Medicine and Radiology) with emphasis on ultrasound imaging (not certified by boards in the U.S.)
- > 14 years of medical practice, all including hands-on ultrasound imaging
- > 50 hours of remote guidance practice in Payload Data Laboratory
- > 20 hours of remotely guided ultrasound with ISS
- **Expertise in abdominal, pelvic, thoracic, superficial, ophthalmic, and musculoskeletal ultrasound**

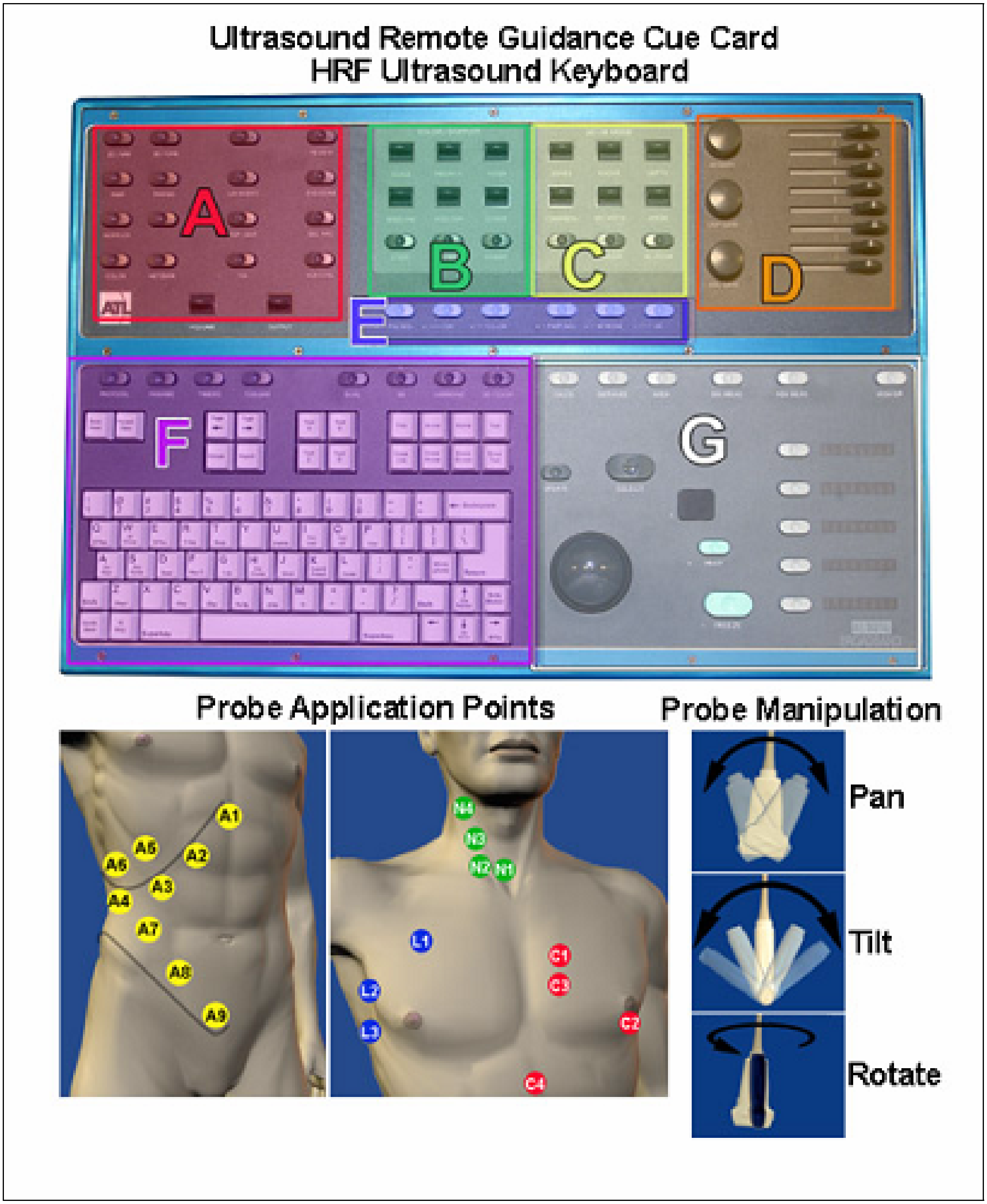
David Martin, Cardiovascular Laboratory, Wyle Laboratories

- Registered Diagnostic Medical Sonographer (RDMS), Registered Diagnostic Cardiovascular Sonographer (RDCS), and Registered Vascular Technologist (RVT)
- 24 years of hands-on scanning
- > 30 hours of remote guidance ultrasound practice in Payload Data Laboratory
- > 20 hours of remote guidance ultrasound practice in Cardiovascular Laboratory
- > 10 hours of remotely guided ultrasound with ISS
- **Expertise in echocardiography, abdominal, superficial, musculoskeletal, and vascular ultrasound**

Kathleen Garcia, Cardiovascular Laboratory, Wyle Laboratories

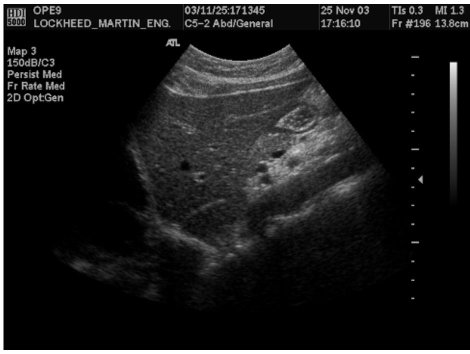
- RDCS and RVT
- 16 years of hands-on scanning
- > 6 hours of remote guidance ultrasound practice in Payload Data Laboratory
- > 1 hour of remotely guided ultrasound with ISS
- **Expertise in echocardiography and vascular ultrasound**

13.4. Appendix 4: ISS Ultrasound Reference Image (aka "Cue Card")



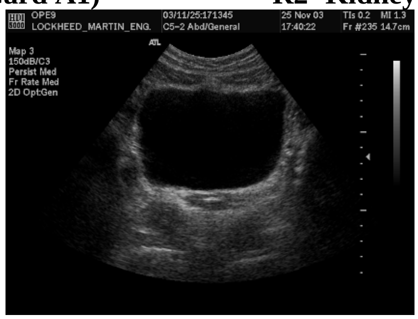
13.5. Appendix 5: Target Image Reference Card (Samples)

ADUM ABDOMINAL REFERENCE IMAGES

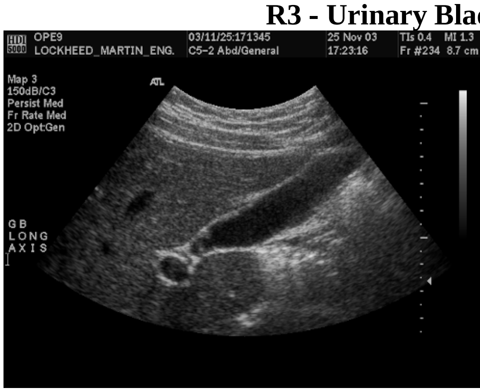


R1- Liver (Ref Card A1)

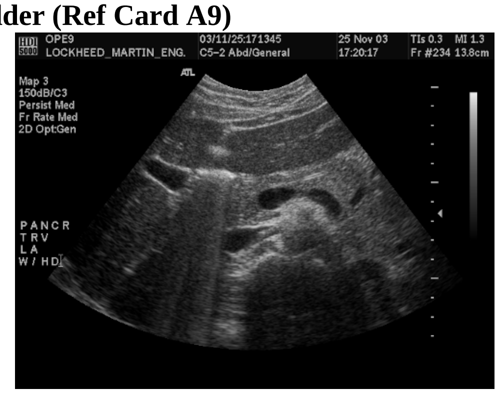
R2 -Kidney (Ref Card A3-4)



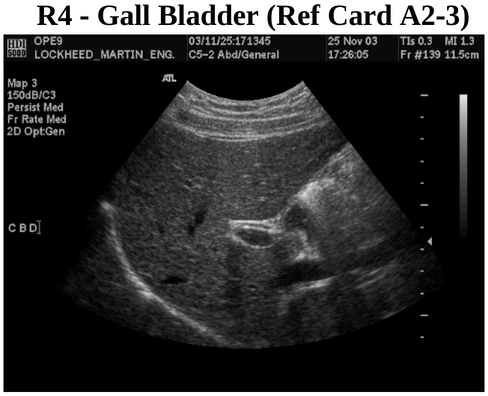
R3 - Urinary Bladder (Ref Card A9)



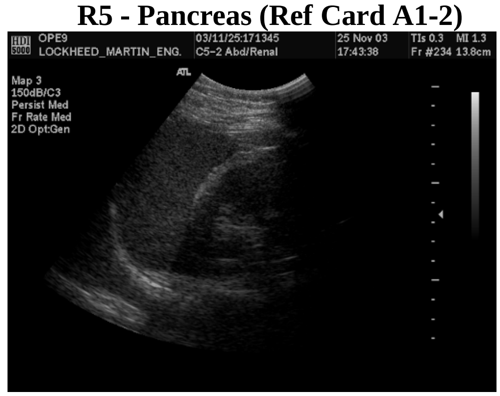
R4 - Gall Bladder (Ref Card A2-3)



R5 - Pancreas (Ref Card A1-2)

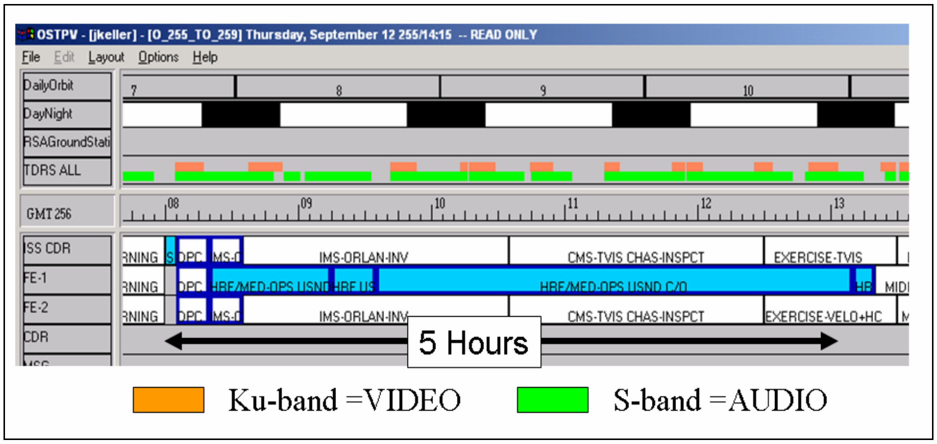


R6 - Common Bile Duct (Verbal)



R7 - Spleen (Ref Card A6L)

13.6. Appendix 6: Sample Communication Timeline



13.7. Appendix 7: ISS Ultrasound Activities Through Expedition 11

September 14, 2002: Medical Operations:
Activation and Check out of the HRF Ultrasound for Medical Contingencies – (ISS-5)

Purpose: Validate procedures, protocols, and hardware operations should ultrasound be needed for a medical contingency.

Summary: The HRF rack containing the Ultrasound System was configured through ground commands by HRF personnel on console in the TSC. The crew member unstowed and connected the keyboard, the monitor, and three probes (designated L12-5, C5-2, and P4-2), and executed the ultrasound power-up sequence per procedures developed specifically for medical operations jointly with HRF. *Real-time video from the ultrasound was transmitted to the ground for the first time*, and was watched on a monitor at the Biomedical MPSR in the Mission Control Center-Houston (MCC-H). Using the video downlink and two-way private space-to-ground audio, an ultrasound expert on the ground remotely guided the crew member through multiple clinical scanning protocols adapted for the zero-g environment and the specific setting of a remotely guided self-examination. During this session, all clinical ultrasound imaging modes were used and all three available probes were tested. A secondary activity was also performed to identify human factors relevant to conducting a two-person ultrasound exam using the CMRS.

Main Results:

- Demonstrated microgravity ultrasound imaging (microgravity sonography) for the first time aboard ISS by a minimally trained, remotely guided astronaut.
- Used near-real-time medical video downlink with full-duplex space-to-ground voice.
- Supported remote feedback and guidance system by minimal training and shared reference tools (“cue card”).
- Validated sonographic protocols adapted for zero g and the specific application of remote guidance.

March 2003: Medical Operations: Microgravity Echocardiography Validation – (ISS-6)

Purpose: Validate all procedures necessary to perform a clinical diagnostic echocardiography exam in microgravity for potential medical contingencies.

Summary: The HRF rack containing the Ultrasound System was configured through ground commands by HRF personnel on console in the TSC. One crew member unstowed and connected the keyboard, the monitor, and the P4-2 probe, and executed the ultrasound power-up sequence. Real-time video from the ultrasound was transmitted to the MCC-H. Using the "privatized" video downlink and two-way private space-to-ground audio, an RDCS (Medical Operations) guided one crew member through real-time cardiac scanning on a second crew member. Time was allowed for the crew members to exchange positions, therefore two echocardiography sessions were completed instead of one. Scanning protocols were based on the American Society of Echocardiography standards. Leading clinicians from Baylor College of Medicine with expertise in cardiology and echocardiography (A. Raizner, M. Quinones) were present to view the data in real time, and to evaluate the data post examination to find them clinically adequate for the majority of acute cardiac conditions possible on ISS.

Main Results:

- Captured clinically valid and interpretable data with a minimally trained and a non-trained user.
- Primarily through analysis of the above data, validated echocardiography procedures modified for zero g, on two subjects, including
    - Hardware and communications procedures.
    - Scanning (data acquisition) protocol.
    - Remote guidance techniques and terminology.
- Identified external clinical experts to review data for clinical validity; provided these external consultants with an opportunity for exposure to operational space-to-ground activity, and assured their willingness to assist NASA Space Medicine in case of relevant medical contingency.

June 2003, HRF: Clinical Image Quality Validation – (ISS-7)

Purpose: Compare quality of real-time video from ultrasound with digital images downlinked after the event.

Summary: The HRF rack containing the Ultrasound System was configured through ground commands by HRF personnel on console at the TSC in the MCC-H. One crew member unstowed and connected the keyboard, the monitor, and the C5-2 and L12-5 probes, and executed the ultrasound power-up sequence. *For the first time, real-time video from the ultrasound was transmitted to the TSC.* The experience of the two previous events was directly used to facilitate this milestone capability. A series of known test patterns was transmitted from the ultrasound system to the ground and recorded for comparison. In addition, using the "privatized" video downlink and two-way private space-to-ground audio, an ultrasound expert guided the crew member through a self exam involving the capture of specific clinical images with anatomical details. Digital images were stored on the ultrasound and real-time video was recorded on the ground. The digital images were downlinked following the activity for comparison with the video. The initial image comparison showed very minimal differences between the digital images and images captured from the real-time video. Further analysis is being done.

Main Results:

- Conducted real-time ultrasound operations with ISS from the TSC for the first time, with private video and audio.
- Validated the capability of HRF ultrasound use in this mode for science.
- Tested and validated ground procedures for this purpose.
- Created a backup capability for medical operations.
- Captured data to measure image quality and to estimate data loss through the ISS video system and communication pathways.

September 2003, HRF:
Feasibility of Exercise Echocardiography in Microgravity –- (ISS-7)

Purpose: Demonstrate the feasibility of performing a stress echocardiography exam on ISS for both medical and research applications.

Summary: The HRF rack containing the Ultrasound System was configured through ground commands by HRF personnel on console at the TSC in the MCC-H. One crew member unstowed and connected the keyboard, the monitor, and the P4-2 probe, and executed the ultrasound power-up sequence. A second crew member configured the cycle ergometer with vibration isolation system (CEVIS) for nominal operations. Both HRF and medical operations personnel were involved and on console at the TSC. Real-time video from the ultrasound was transmitted to the TSC. Using the "privatized" video downlink and two-way private space-to-ground audio, an RDCS) with remote guidance experience (medical operations) guided one crew member through real-time cardiac scanning on a second crew member while resting on the CEVIS, then while pedaling at slow, medium, and fast rates. Scanning protocols were based on the American Society of Echocardiography standards.

Main Results:

- Captured clinically valid and interpretable stress (exercise) echocardiography data with a minimally trained and an untrained operator using remote real-time guidance.
- Identified constraints and limitations of the procedures, hardware configurations, and human factors associated with stress (exercise) echocardiography on ISS.
- Determined that it would be feasible to conduct stress (exercise) echocardiography on ISS should it be indicated or necessary for research purposes, and modifications were identified for the procedures employed during the activity.

March 2004 – March 2005, HRF:
Advanced Diagnostic Ultrasound in Microgravity – (ISS-8, 9, 10)

Official information on the ADUM experiment is available on the following NASA Web site: http://hrf.jsc.nasa.gov/science/default.asp?e_id=4. Additional information may be requested from the ADUM experiment Principal Investigator Scott A. Dulchavsky, MD, PhD, at: sdulcha1@hfhs.org.

The information for this section was prepared by Space Medicine Operational Ultrasound Team.

- Shannon Melton, SMelton@wylehou.com, (281) 212-1435
- Ashot Sargsyan, ASargsyan@wylehou.com, (281) 212-1388
- Douglas Hamilton, DHamilton@wylehou.com, (281) 212-1391

Additional information about the above listed and other activities from the HRF perspective, as well as details of HRF-related information, can be requested from

- Ms. Cynthia Haven, HRF Project Manager, cynthia.p.haven@nasa.gov, 281-483-6045.
- Ms. Jacqui van Twest, HRF, jacqui.vantwest@lmco.com, 281-218-3072.

13.8. Appendix 8: Associated Documentation

References to the internal NASA and International Space Station Program documentation are withheld in this section as they are not available from normal bibliographic sources. Revisions to these documents are made on a regular basis. Users of ISS Ultrasound that are "internal" to

NASA and the ISS Partnership have access to the documentation, and will obtain necessary information through the HRF points-of-contact. Potential "external" users will be provided necessary information by HRF in early phases of the consideration of the given research program.

13.9. Appendix 9: Selected Relevant Publications

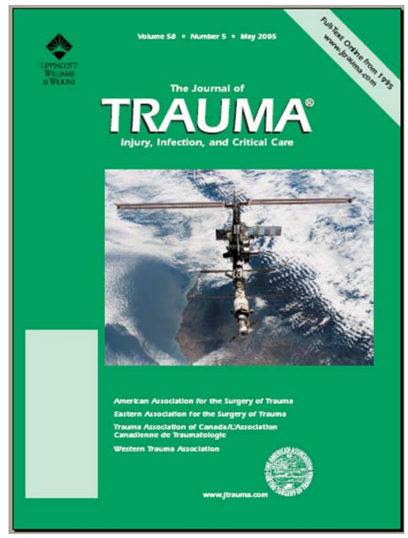
JOURNAL ARTICLES BY AUTHORS

1. Sargsyan AE, Hamilton DR, Jones JA, Melton S, Whitson PA, Kirkpatrick AW, Martin D, Dulchavsky SA FAST at MACH 20: clinical ultrasound aboard the International Space Station. J Trauma. 2005 Jan;58(1):35-9.

    BACKGROUND: Focused assessment with sonography for trauma (FAST) examination has been proved accurate for diagnosing trauma when performed by nonradiologist physicians. Recent reports have suggested that nonphysicians also may be able to perform the FAST examination reliably. A multipurpose ultrasound system is installed on ISS as a component of the HRF. Nonphysician crew members aboard ISS receive modest training in hardware operation, sonographic techniques, and remotely guided scanning. This report documents the first FAST examination conducted in space, as part of the sustained effort to maintain the highest possible level of available medical care during long-duration space flight. **METHODS:** An ISS crew member with minimal sonography training was remotely guided through a FAST examination by an ultrasound imaging expert from the MCC using private real-time two-way audio and a private space-to-ground video downlink (7.5 frames/se). There was a 2-second satellite delay for both video and audio. To facilitate the real-time telemedical ultrasound examination, identical reference cards showing topologic reference points and hardware controls were available to both the crew member and the ground-based expert. **RESULTS:** A FAST examination, including four standard abdominal windows, was completed in approximately 5.5 minutes. Following commands from the MCC-based expert, the crew member acquired all target images without difficulty. The anatomic content and fidelity of the ultrasound video were excellent and would allow clinical decision making. **CONCLUSIONS:** It is possible to conduct a remotely guided FAST examination with excellent clinical results and speed, even with a significantly reduced video frame rate and a 2-second communication latency. A wider application of trauma ultrasound applications for remote medicine on Earth appears to be possible and warranted.

2. Chiao L, Sharipov S, Sargsyan A, Melton S, Hamilton D, McFarlin K, Dulchavsky S, Ocular Examination for Trauma; Clinical Ultrasound Aboard the International Space Station. J Trauma. 2005 May;58(5):885-9. (Featured article).

    BACKGROUND: Ultrasound imaging is a successful modality in a broad variety of diagnostic applications including trauma. Ultrasound has been shown to be accurate when performed by non-radiologist physicians; recent reports have suggested that nonphysicians can perform limited ultrasound examinations. A multipurpose ultrasound system is installed on ISS as a component of the HRF. This report documents the first ocular ultrasound examination conducted in space, which demonstrated the capability to assess physiologic alterations or pathology including trauma during long-duration space flight. **METHODS:** An ISS crew member with minimal sonography training was remotely guided by an imaging expert from the MCC through a comprehensive ultrasound examination of the eye. A multipurpose ultrasound imager was used in conjunction with a space-to-ground video downlink and two-way audio. Reference cards with topological reference points, hardware controls, and target images were used to facilitate the examination. Multiple views of the eye structures were obtained through a closed eyelid. Pupillary response to light was demonstrated by modifying the light exposure of the contralateral eye. **RESULTS:** A crew member on ISS was able to complete a comprehensive ocular examination using B- and M-mode ultrasonography with remote guidance from an expert in the MCC. Multiple anteroposterior, oblique, and coronal views of the eye clearly demonstrated the anatomic structures of both segments of the globe. The iris and pupil were readily visualized with probe manipulation. Pupillary diameter was assessed in real time in B- and M-mode displays. The anatomic detail and fidelity of ultrasound video were excellent and could be used to answer a variety of clinical and space physiologic questions. **CONCLUSIONS:** A comprehensive, high-quality ultrasound examination of the eye was performed with a multipurpose imager aboard ISS by a nonexpert operator using remote guidance. Ocular ultrasound images were of diagnostic quality despite the 2-second communication latency and the unconventional setting of a weightless spacecraft environment. The remote guidance techniques developed to facilitate this successful NASA research experiment will support wider applications of ultrasound for remote medicine on Earth, including the assessment of pupillary reactions in patients with severe craniofacial trauma and swelling.



3. Foale CM, Kaleri AY, Sargsyan AE, Hamilton DR, Melton S, Martin D, Dulchavsky SA. Diagnostic Instrumentation Aboard ISS: Just-In-Time Training for Non-Physician Crewmembers. Aviat Space Environ Med. 2005 Jun;76(6):594-8.

INTRODUCTION: The performance of complex tasks on ISS requires significant preflight crew training commitments and frequent skill and knowledge refreshment. This report documents a recently developed “just-in-time” training methodology, which integrates preflight hardware familiarization and procedure training with an on-orbit CD-ROM-based skill enhancement. This “just-in-time” concept was used to support real-time remote expert guidance to complete ultrasound examinations using the ISS HRF. **METHODS:** An American and a Russian ISS crew member received 2 hours of hands-on ultrasound training 8 months prior to the on-orbit ultrasound exam. A CD-ROM-based on-board proficiency enhancement (OPE) interactive multimedia program, consisting of memory enhancing tutorials and skill testing exercises, was completed by the crew member 6 days prior to the on-orbit ultrasound exam. The crew member was then remotely guided through a thoracic, vascular, and echocardiographic examination by ultrasound imaging experts. **RESULTS:** Results of the CD-ROM-based OPE session were used to modify the instructions during a complete 35-minute real-time thoracic, cardiac, and carotid/jugular ultrasound study. Following commands from the ground-based expert, the crewmember acquired all target views and images without difficulty. The anatomical content and fidelity of ultrasound video were adequate for clinical decision making. **CONCLUSIONS:** Complex ultrasound experiments with expert guidance were performed with high accuracy following limited preflight training and multimedia based in-flight review, despite a 2-second communication latency. In-flight application of multimedia proficiency enhancement software, coupled with real-time remote expert guidance, facilitates the successful performance of ultrasound examinations on orbit and may have additional terrestrial and space applications.

4. Hamilton DR, Sargsyan AE, Kirkpatrick AW, Nicolaou S, Campbell MR, Dawson D, Melton S, Beck G, Guess T, Rasbury J, Dulchavsky SA. Sonographic detection of pneumothorax and hemothorax in microgravity. Aviat. Space. Environ. Med. 75; 272-277, 2004.

   INTRODUCTION: An intrathoracic injury may be disastrous to a crew member aboard ISS if the diagnosis is missed or delayed. Symptomatic or clinically suspicious thoracic trauma is treated as a surgical emergency on Earth, usually with immediate stabilization and rapid transport to a facility that is able to deliver the appropriate medical care. A similar approach is planned for ISS; however, an unnecessary evacuation would cause a significant mission impact and an exorbitant expense. **HYPOTHESIS:** The use of ultrasound imaging for the detection of pneumothorax and hemothorax in microgravity is both possible and practical. **METHODS:** Sonography was performed on anesthetized pigs in a ground-based laboratory (n = 4) and microgravity conditions (zero g) during parabolic flight (n = 4). Aliquots of air (50–500 ml) or saline (10–200 ml) were introduced into the pleural space to simulate pneumothorax and hemothorax, respectively. **RESULTS:** The presence of “lung sliding” excluded pneumothorax. In microgravity, a loss of “lung sliding” was noted simultaneously in the anterior and posterior sonographic windows after 100 ml of air was introduced into the chest, indicating pneumothorax. The presence of the fluid layer in simulated hemothorax was noted in the anterior and posterior sonographic windows after 50 ml of fluid were injected into the pleural space. During the microgravity phase, the intrapleural fluid rapidly redistributed so that it could be detected using either anterior or posterior sonographic windows. **CONCLUSION:** Modest to severe pneumothorax and hemothorax can be diagnosed using ultrasound in microgravity.

5. Dulchavsky, SA; Schwarz, KL; Kirkpatrick, AW; Billica, RD; Williams, DR; Diebel, LN; Campbell, MR; Sargsyan, AE; Hamilton, DR Prospective evaluation of thoracic ultrasound in the detection of pneumothorax Journal Of Trauma-Injury Infection and Critical Care, 2001 Feb 50(2) 201–5.

   BACKGROUND: Thoracic ultrasound may rapidly diagnose pneumothorax when radiographs are unobtainable; the accuracy is not known. **METHODS:** We prospectively evaluated thoracic ultrasound detection of pneumothorax in patients at high suspicion of pneumothorax. The presence of "lung sliding" or "comet tail" artifacts was determined in patients by ultrasound before radiologic verification of pneumothorax by residents instructed in thoracic ultrasound. Results were compared with standard radiography. **RESULTS:** There were 382 patients enrolled; the cause of injury was blunt (281 of 382), gunshot wound (22 of 382), stab wound (61 of 382), and spontaneous (18 of 382). Pneumothorax was demonstrated on chest radiograph in 39 patients and confirmed by ultrasound in 37 of 39 patients (95% sensitivity); two pneumothoraces could not be diagnosed because of subcutaneous air; the true-negative rate was 100%. **CONCLUSION:** Thoracic ultrasound reliably diagnoses pneumothorax. Expansion of the FAST examination to include the thorax should be investigated for terrestrial and space medical applications.

6. Fincke EM, Padalka G, Lee D, van Holsbeeck M, Sargsyan AE, Hamilton DR, Martin D, Melton SL, Dulchavsky SA. Evaluation of shoulder integrity in space: first report of musculoskeletal ultrasound on the International Space Station. Radiology. 2005 Feb;234(2):319-22. Epub 2004 Nov 8.

    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 the nonphysician crew member 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 ISS. Expedition 9 crew members attended a 2.5-hour didactic and hands-on US training session 4 months before launch. Aboard ISS, they completed a 1-hour computer-based OPE program 7 days before examination. Crew members did not receive specific training in shoulder anatomy or shoulder US techniques. Evaluation of astronaut shoulder integrity was done by using an HRF 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 the TSC at JSC. Probe manipulation and equipment adjustments were guided with verbal commands from remote sonologists to astronaut operators to complete rotator cuff evaluation. Comprehensive US of crew member'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. Post-session download and analysis of high-fidelity US images collected on board 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 crew members 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. (c) RSNA, 2004.

7. Melton S, Beck G, Hamilton D, Chun R, Sargsyan A, Nicolaou S, Campbell MR, Dulchavsky S, Dawson D, Kirkpatrick AW. How to test a medical technology for space: trauma sonography in microgravity. Mil. Med 2003;168:312-313.

8. Sargsyan AE., Hamilton DR, Nicolaou S, Kirkpatrick AW, Campbell MR, Billica RD, Dawson D, Williams DR, Melton SL, Beck G, Forkheim K, Dulchavsky SA Ultrasound evaluation of the magnitude of pneumothorax: a new concept, Am Surg 2001:67(3):232-5.

   Pneumothorax is commonly seen in trauma patients; the diagnosis is confirmed by radiography. The use of ultrasound where radiographic capabilities are absent is being investigated by NASA. We investigated the ability of ultrasound to assess the magnitude of pneumothorax in a porcine model. Sonography was performed on anesthetized pigs in both ground-based laboratory (n = 5) and microgravity conditions (zero g) aboard the KC-135 aircraft during parabolic flight (n = 4). Aliquots of air (50–100 cm^3) were introduced into the chest to simulate pneumothorax. Results were videotaped and digitized for later interpretation. Several distinct sonographic patterns of partial lung sliding were noted including the combination of a sliding zone with a still zone and a “segmented” sliding zone. These “partial lung sliding” patterns exclude massive pneumothorax manifested by a complete separation of the lung from the parietal pleura. In zero g, the sonographic picture is more diverse; one g differences between posterior and anterior aspects are diminished. Modest pneumothorax can be inferred by the ultrasound sign of “partial lung sliding.” This finding, which increases the negative predictive value of thoracic ultrasound, may be attributed to intermittent pleural contact, small air spaces, or alterations in pleural lubricant. Further studies of these phenomena are warranted.

9. Marshburn TH, Legome E, Sargsyan AE, Melton SM, Li J, Noble VA, Dulchavsky SA, Sims C, Robinson D. Goal directed ultrasound in the detection of long-bone fractures. J. Trauma 57(2):329-332, 2004.

   BACKGROUND: New portable US systems are capable of detecting fractures in the remote setting. However, the accuracy of ultrasound by physicians with minimal ultrasound training is unknown. **METHODS:** After one hour of standardized training, physicians with minimal US experience clinically evaluated patients presenting with pain and trauma to the upper arm or leg. The investigators then performed a long-bone US evaluation, recording their impression of fracture presence or absence. Results of the examination were compared with routine plain or computer-aided radiography (CT). **RESULTS:** 58 patients were examined. The sensitivity and specificity of US were 92.9% and 83.3%, and of the physical examination were 78.6% and 90.0%, respectively. US provided improved sensitivity with less specificity compared with physical examination in the detection of fractures in long bones. **CONCLUSION:** US scans by minimally trained clinicians may be used to rule out a long-bone fracture in patients with a medium to low probability of fracture.

10. Hamilton, D.W., Sargsyan, A. , Nicolaou, S., Dulchavsky, S., Dawson, D., Kirkpatrick, A., Campbell, M., McDonald, V., Beck, G., and Melton, S.L. Remote diagnosis and treatment of illness and injury using ultrasound on the International Space Station. Telemedicine Journal and e-Health, 2001 Summer 7(2):131.

11. Melton, S.L., Hamilton, D., Martin, D., and Sargsyan, A. Remote ultrasound diagnosis for the International Space Station. Telemedicine Journal and e-Health 2001 Summer 7(2):132.

12. Kirkpatrick AW, Nicolaou S, Sargsyan AE, Melton S, Beck G, Hamilton DR, Campbell MR, Dulchavsky SA, Feiveson A, Dawson DL. Focused assessment with sonography for trauma in weightlessness. J Am Coll Surg 2003;196:833-844.

BACKGROUND: The FAST searches for fluid in gravitationally dependent regions. There is no prior experience with this technique in weightlessness, such as on ISS, where sonography is currently the only diagnostic imaging tool. **STUDY DESIGN:** A ground-based (one-g) porcine model for sonography was developed. We examined both the feasibility and the comparative performance of the FAST examination in parabolic flight. Sonographic detection and fluid behavior were evaluated in four animals during alternating weightlessness (zero g) and hypergravity (1.8g) periods. During flight, boluses of fluid were incrementally introduced into the peritoneal cavity. Standardized sonographic windows were recorded. Postflight, the video recordings were divided into 169 20-second segments for subsequent interpretation by 12 blinded ultrasonography experts. Reviewers first decided whether a video segment was of sufficient diagnostic quality to analyze (determinate). Determinate segments were then analyzed as containing or not containing fluid. A probit regression model compared the probability of a positive fluid diagnosis to actual fluid levels (0–500 ml) under both zero-g and 1.8g conditions. **RESULTS:** The in-flight sonographers found real-time scanning and interpretation technically similar to that of terrestrial conditions, as long as restraint was maintained. On blinded review, 80% of the recorded ultrasound segments were considered determinate. The best sensitivity for diagnosis in zero g was found to be from the subhepatic space, with probability of a positive fluid diagnosis ranging from 9% (no fluid) to 51% (500 ml fluid). **CONCLUSIONS:** The FAST examination is technically feasible in weightlessness, and merits operational consideration for clinical contingencies in space.

13. Kirkpatrick AQ, Nicolaou S, Campbell MR, Sargsyan AE, Dulchavsky SA, Melton S, Beck G, Dawson DL, Billica RD, Johnston SL, Hamilton DR. Percutaneous aspiration of intra-peritoneal fluid in weightlessness: a potential component of the management of peritonitis in space. Aviat Space Environ Med 2002;73:925-930.

BACKGROUND: As a medical emergency that can affect even well-screened, healthy individuals, peritonitis developing during a long-duration space exploration mission may dictate deviation from traditional clinical practice due to the absence of otherwise indicated surgical capabilities. Medical management can treat many intra-abdominal processes, but treatment failures are inevitable. In these circumstances, percutaneous

aspiration under sonographic guidance could provide a “rescue” strategy. Hypothesis: Sonographically guided percutaneous aspiration of intra-peritoneal fluid can be performed in microgravity. **METHODS:** Investigations were conducted in the microgravity environment of NASA’s KC-135 research aircraft (zero g). The subjects were anesthetized female Yorkshire pigs weighing 50 kg. The procedures were rehearsed in a terrestrial animal lab (one g). Colored saline (500 ml) was introduced through an intra-peritoneal catheter during flight. A high-definition ultrasound system (HDI-5000, ATL, Bothell, Wash.) was used to guide a 16-gauge needle into the peritoneal cavity to aspirate fluid. **RESULTS:** Intra-peritoneal fluid collections were easily identified, distinct from surrounding viscera, and on occasion became more obvious during weightless conditions. Subjectively, with adequate restraint of the subject and operators, the procedure was no more demanding than during the one-g rehearsals. **CONCLUSIONS:** Sonographically guided percutaneous aspiration of intra-peritoneal fluid collections is feasible in weightlessness. Treatment of intra-abdominal inflammatory conditions in space flight might rely on pharmacological options, backed by sonographically guided percutaneous aspiration for the “rescue” of treatment failures. While this risk mitigation strategy cannot guarantee success, it may be the most practical option given severe resource limitations.

14. Chun R, Kirkpatrick AW, Sirois M, Sargsyan AE, Melton S, Peng; Hamilton DR, Dulchavsky SA. Where’s the Tube? Evaluation of Hand-held Ultrasound in Confirming Endotracheal Tube Placement. Prehopsital and Disaster Medicine, 2004; 19(4):366-369.

INTRODUCTION: The diagnosis of endotracheal tube (ETT) mal-position may be delayed in extreme environments. Several methods are used to confirm proper ETT placement, but these methods can be unreliable or unavailable in certain settings. Thoracic sonography, previously used to detect pneumothoraces, has not been tested to assess ETT placement. **HYPOTHESIS:** Thoracic sonography could correlate with pulmonary ventilation and, thereby, help to confirm proper ETT placement. **METHODS:** Thirteen patients requiring elective intubation under general anesthesia and data from two trauma patients were evaluated. Using a portable, hand-held ultrasound (PHHU) machine, sonographic recordings of the chest wall visceral-parietal pleural interface (VPPI) were recorded bilaterally in each patient during all phases of airway management: (1) pre-oxygenation; (2) induction; (3) paralysis; (4) intubation; and (5) ventilation. **RESULTS:** The VPPI could be well-imaged for all of the patients. In the two trauma patients, right main stem intubations were noted in which specific pleural signals were not seen in the left chest wall VPPI after tube placement. These signs returned after correct repositioning of the ETT. In all of the elective surgery patients, signs correlating with bilateral ventilation in each patient were imaged and correlated with confirmation of ETT placement by anesthesiology. **CONCLUSIONS:** This report raises the possibility that thoracic sonography may be another tool that could be used to confirm proper ETT placement. This technique may have merit in extreme environments, such as in remote, pre-hospital settings or during aerospace medical transports, in which auscultation is impossible due to noise, or capnography is not available, and, thus, requires further scientific evaluation.

15. McFarlin K, Sargsyan AE, Melton S, Hamilton DR, Dulchavsky SA. A surgeon's guide to the universe. Surgery. 2006 May;139(5):587-90.

16. Kirkpatrick AW, Dulchavsky SA, Boulanger BR, Campbell MR, Hamilton DR, Dawson DL, Williams DR. Extraterrestrial resuscitation of hemorrhagic shock: fluids. J Trauma. 2001 Jan;50(1):162-8.

17. Kirkpatrick AW, Campbell MR, Jones JA, Broderick TJ, Ball CG, McBeth PB, McSwain NE, Hamilton DR, Holcomb JB. Extraterrestrial hemorrhage control: terrestrial developments in technique, technology, and philosophy with applicability to traumatic hemorrhage control in long-duration spaceflight. J Am Coll Surg. 2005 Jan;200(1):64-76.

18. Sarkisian (Sargsyan) AE, Khondkarian RA, Amirbekian NM, Bagdasarian NB, Khojayan RL, Oganesian YT. Sonographic screening of mass casualties for abdominal and renal injuries following the 1988 Armenian earthquake. J Trauma. 1991 Feb;31(2):247-50.

The value of sonography in acute trauma evaluation is generally underestimated, and the opinions are controversial. Sonography was performed as a primary screening procedure in 400 of 750 mass casualty patients with trauma admitted to a large hospital within the first 72 hours after the 1988 Armenian earthquake. Two real-time sector scanners were used in the reception area of the hospital, and the average time spent on one patient was 4 minutes. More than 130 follow-up sonographic examinations were required. Trauma-associated pathology of the abdomen and retroperitoneal space was detected in 12.8% of the patients, with 1% false negatives and no false positives. The authors believe that sonographic screening of mass casualties is a quick and effective means for detection of abdominal and retroperitoneal injuries. Sonography should be used for this purpose more routinely to gain experience and maintain preparedness of sonographers for screening of trauma cases in mass casualty situations.

19. Houtchens BA, Clemmer TP, Holloway HC, Kiselev AA, Logan JS, Merrell RC, Nicogossian AE, Nikogossian HA, Rayman RB, Sarkisian (Sargsyan) AE, et al. Telemedicine and international disaster response. Medical consultation to Armenia and Russia via a Telemedicine Spacebridge. Prehospital Disaster Med. 1993 Jan-Mar;8(1):57-66.

The Telemedicine Spacebridge, a satellite-mediated, audio-video-fax link between four U.S. and two Armenian and Russian medical centers, permitted remote U.S. consultants to assist Armenian and Russian physicians in the management of medical problems following the December 1988 earthquake in Armenia and the June 1989 gas explosion near Ufa. **Methods:** During 12 weeks of operations, 247 Armenian and Russian and 175 U.S. medical professionals participated in 34 half-day clinical conferences. A total of 209 patients were discussed, requiring expertise in 20 specialty areas. **Results:** Telemedicine consultations resulted in altered diagnoses for 54, new diagnostic studies for 70, altered diagnostic processes for 47, and modified treatment plans for 47 of 185 Armenian patients presented. Simultaneous participation of several U.S. medical centers was judged beneficial; quality of data transmission was judged excellent. **Conclusion:** These results suggest that interactive consultation by remote specialists can provide valuable assistance to on-site physicians and favorably influence clinical decisions in the aftermath of major disasters.

20. A. E. Sargsyan, C. R. Doarn, and S. C. Simmons. Internet and World Wide Web Technologies for Medical Data Management and Remote Access to Clinical Expertise. Aviat Space Environ Med. 1999 Feb;70(2):185-90.

21. Aucar JA, Doarn CR, Sargsyan A, Samuelson DA, Odonnell MJ, DeBakey ME. Use of the Internet for long-term clinical follow-up. Telemed J. 1998 Winter;4(4):371-4.

    Use of the Internet for patient-specific consultation across international boundaries has been demonstrated. This report describes the efforts of Baylor College of Medicine and NASA to conduct a telemedicine consultation with Moscow, Russia. Consultation between Russian and U.S. physicians was performed over the Internet with a combination of real-time and store-and-forward techniques. The clinical focus involved a 65-year old Russian scientist who had undergone mitral valve replacement in the U.S. 5 years earlier. Development of new activity related chest pain, dyspnea, and intermittent atrial fibrillation led to a consultation with his U.S. cardiologist and cardiac surgeon. Real-time video was supplemented with telephone voice communication to overcome bandwidth limitations. Prior to the video link, the patient’s recent history and clinical data were made available via the Internet using file transfer protocol (FTP). The patient’s medications, new electrocardiographic findings, and activity status were reviewed. Specific clinical recommendations were made as a result of this telemedicine consultation. This case illustrates the technical factors, clinical implications, and confidentiality issues related to using the Internet for telemedicine consultations and demonstrates that the Internet may provide an alternative means for long-term clinical follow-up of patients.

22. Beck G, Melton S, Dulchavsky SA. Critical care medicine in space. Aviat Space Environ Med. 2005 Feb;76(2):163.

OTHER PUBLICATIONS BY AUTHORS

BOOK CHAPTERS

1. Hamilton DR. Chapter: Cardiovascular disease. In: Principles of Clinical Medicine for Space Flight. Barratt MR , Pool SL (Eds.). Springer Verlag; in press (2006).
2. Sargsyan AE. Chapter: Medical Imaging. In: Principles of Clinical Medicine for Space Flight. Barratt MR , Pool SL (Eds.). Springer Verlag; in press (2006).
3. Simmoms SC, Hamilton DR, McDonald PV. Chapter: Telemedicine. In: Principles of Clinical Medicine for Space Flight. Barratt MR , Pool SL (Eds.). Springer Verlag; in press (2006).
4. Billica, RD, Voronkov, YI, Sargsyan AE, and Voronin, LE. Medical Monitoring Before and After Flight. In: Space Biology and Medicine, A. Nicogossian et al. (Ed.),Vol. 4: Health, Performance and Safety of Space Crews. pp. 43-59.

NASA PUBLICATIONS

1. Sargsyan A, Melton S, Hurst V, Martin D. Evaluation of Human Factors, Interfaces, and Remote Guidance Techniques for Collection of Ultrasound Images in Microgravity, NASA CR 208932, KC-135 and Other Microgravity Simulations Summary Report, NASA Aug 2002.
2. Melton S, Sargsyan A, Martin D, Hamilton D, Moghaddam A. Measuring Fluid Shifts in the Vascular System with Ultrasound During Parabolic Flight. NASA CR 208936, KC-135 and Other Microgravity Simulations Summary Report, NASA, Aug 2003.
3. Melton SL, Sargsyan AE: Evaluation of Human Research Facility Ultrasound with the ISS Video system. NASA Technical Publication 2003-212056.
4. Dulchavsky S, Sargsyan A, Melton S, Hamilton D, Beck G. Minimally Invasive Diagnosis and Therapy of Microgravity Medical Contingencies. NASA CR 208940, KC-135 and Other Microgravity Simulations Summary Report, NASA, Aug 2004.

SELECTED PRESENTATIONS

1. A.E. Sargsyan, S.A. Dulchavsky, J.A. Jones, D.R. Hamilton, S.K. Roden, S.L. Melton, D. Martin, K. Garcia, J.M. Duncan. Abdominal Imaging with Ultrasound on the International Space Station. AsMA 77th Annual Scientific Meeting, May 14-18, 2006, Orlando, Fla. In: AsMA 2006 Meeting Abstracts, Aviation, Space, and Environmental Medicine, 2006 March, 77(3), p.277
2. K. McFarlin, A.E. Sargsyan, S.L. Melton, D.R. Hamilton, S.A. Dulchavsky. Non-Physician Thoracic Ultrasound for Trauma. AsMA 77th Annual Scientific Meeting, May 14-18, 2006, Orlando, Fla. In: AsMA 2006 Meeting Abstracts, Aviation, Space, and Environmental Medicine, 2006 March, 77(3), p.230.
3. A.E. Sargsyan, S.A. Dulchavsky, D.R. Hamilton, S.K. Roden, S.L. Melton, D. Martin, K. Garcia, J.M. Duncan. Mulculoskeletal Diagnostic Imaging with Ultrasound on the International Space Station. AsMA 77th Annual Scientific Meeting, May 14-18, 2006, Orlando, Fla. In: AsMA 2006 Meeting Abstracts, Aviation, Space, and Environmental Medicine, 2006 March, 77(3), p.334.
4. D.R. Hamilton, J. Polk, C. Van Velson, B. Temple, M. Christensen, and H. Better. "Sim as you fly and fly as you sim" debrief of an ISS medical deorbit simulation. AsMA 77th Annual Scientific Meeting, May 14-18, 2006, Orlando, Fla. In: AsMA 2006 Meeting Abstracts, Aviation, Space, and Environmental Medicine, 2006 March, 77(3), p.276.
5. J.A. Jones, D.R. Hamilton, and R.A. Scheuring. CEV/Lunar medical contingency management and medical care systems. AsMA 77th Annual Scientific Meeting, May 14-18, 2006, Orlando, Fla. In: AsMA 2006 Meeting Abstracts, Aviation, Space, and Environmental Medicine, 2006 March, 77(3), p.284-5.
6. Ashot Sargsyan, M.D., Wyle Life Sciences: Ultrasound Imaging Aboard the ISS: A Review of Experience to Date. In: UTMB/JSC Aerospace Medicine Residency Program Space Medicine Grand Rounds, Houston, Texas, July 26, 2005: http://www.dsls.usra.edu/archive_2005.html (Cat.A PRA CME lecture by University of Texas Medical Branch (UTMB)).

7. Ashot E. Sargsyan, M.D. and Douglas W. Hamilton, M.D., Ph.D. Wyle Laboratories Life Sciences Systems & Services: Diagnostic Ultrasound Imaging in Space. In: UTMB/JSC Aerospace Medicine Residency Program Space Medicine Grand Rounds, Houston, Texas, October 24, 2000, http://www.dsls.usra.edu/archive_2000.html (Cat A CME lecture by UTMB).
8. Ashot E. Sargsyan Diagnostic Ultrasound Imaging on ISS: A Review of Today's Capability. Aerospace Medicine Grand Rounds, Baylor College of Medicine, Houston, Texas, NASA Lyndon B. Johnson Space Center Aug 29, 2005 (Cat A CME lecture by the Baylor College of Medicine).
9. Melton, S., Jones, J., Hamilton, D., Meir, J., Hurst, V., Sargsyan, A. Activation and checkout of the Human Research Facility (HRF) Ultrasound for Medical Contingencies on the International Space Station (ISS) Bulletin of Aerospace Medicine Association 74th Annual Scientific Meeting San Antonio, Texas, May 5, 2003.
10. Sargsyan, A., Hamilton, D., Jones, J., Martin, D., Whitson, P., Melton, S. Clinical capability enhancement with diagnostic ultrasound imaging aboard the International Space Station (ISS) Bulletin of Aerospace Medicine Association 74th Annual Scientific Meeting San Antonio, Texas, May 7, 2003.
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13. ABSTRACT *(Maximum 200 words)*

The feasibility of ultrasonic imaging in human space flight has been demonstrated on NASA and Russian spacecraft. Several ultrasound systems have been successfully operated by both physician and non-physician astronauts and cosmonauts in pre-International Space Station (ISS) space flights, yielding valuable scientific information. A multipurpose ultrasound system was adapted for space and installed aboard ISS to continue human research in microgravity environments at a new level of sophistication and fidelity. Alone or in combination with other components of the Human Research Facility (HRF), this system provides a research capability never before available in space. The system can operate in B, M, Color Doppler, Power Angiography, Flow Propagation, Pulsed Spectral Doppler, and Continuous Wave Doppler modes and their combinations. Thus, the HRF Ultrasound System allows the realization of the great scientific potential of ultrasound imaging in conditions of space flight, acquiring morphological/morphometric and physiological/functional information from virtually every area or organ system of the human body. This will now allow ultrasound to be used in space for medical risk mitigation and has driven the medical concept of operations to recognize and treat as many medical conditions as possible while on orbit, delaying or avoiding return to a definitive medical care facility.

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