Diagnostic Imaging in the Medical Support Of the Future Missions to the Moon

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Educational Objectives

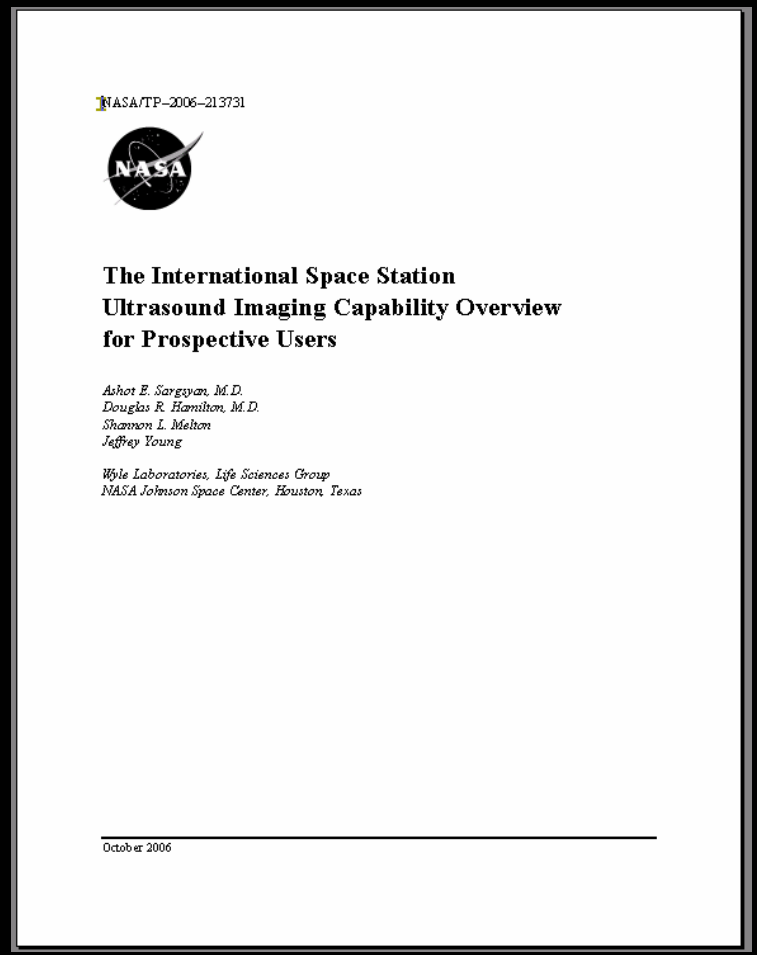
- 1) Update the audience on the current experience in ultrasound imaging in space flight
- 2) Discuss the unique aspects of conducting ultrasound imaging on ISS, interplanetary transit, and lunar surface operations
- 3) Review preliminary data obtained in simulations of medical imaging in lunar surface operations

Pre-lecture test

- What imaging experience on ISS do we have?
- Which clinical imaging applications are currently available to the ISS Surgeon on console?
- Are there any obvious differences among 0G, 1/6G, and 1G imaging anatomy?
- How does the ISS experience relate to Exploration?
- What are the design options for putting and operating an ultrasound system in a spacecraft or habitat on the lunar surface?

LEO Ultrasound

Of the many imaging modalities, ultrasound has been the only one found suitable for use in low-Earth orbit.



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The International Space Station Ultrasound Imaging Capability Overview for Prospective Users

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ISS Ultrasound Operations

	Hours of Operation
MedOps / HRF	20
Research	85
Total	105

ISS Ultrasound Overview

Ultrasound imaging has been placed among the ISS operational medical requirements;

Most clinical applications are considered feasible, although evidence is partial or indirect:

- *ISS evidence with healthy subjects*
- *KC-135 (or C-9) data with healthy subjects*
- *KC-135 (or C-9) data on animal models of disease and trauma*
- *Quality and completeness of ISS ultrasound data have been judged acceptable for diagnostic purposes*

Principles of Remote Ultrasound

Distributed Expertise

between crew, ground experts, and digital resources

Common Knowledge Base

pre-mission training material

just-in-time training material

general procedures

application-specific focused protocols

target views and images

terminology

demonstrations photo and video,tips and hints

Principles of Remote Ultrasound

Clear Identification of Responsibility

between crew and ground experts

Clinical and Operational Subordination

studies are ordered by the Crew Surgeon when clinically indicated and operationally practical

imaging experts are subordinated to the ISS Crew Surgeon

Principles of Remote Ultrasound

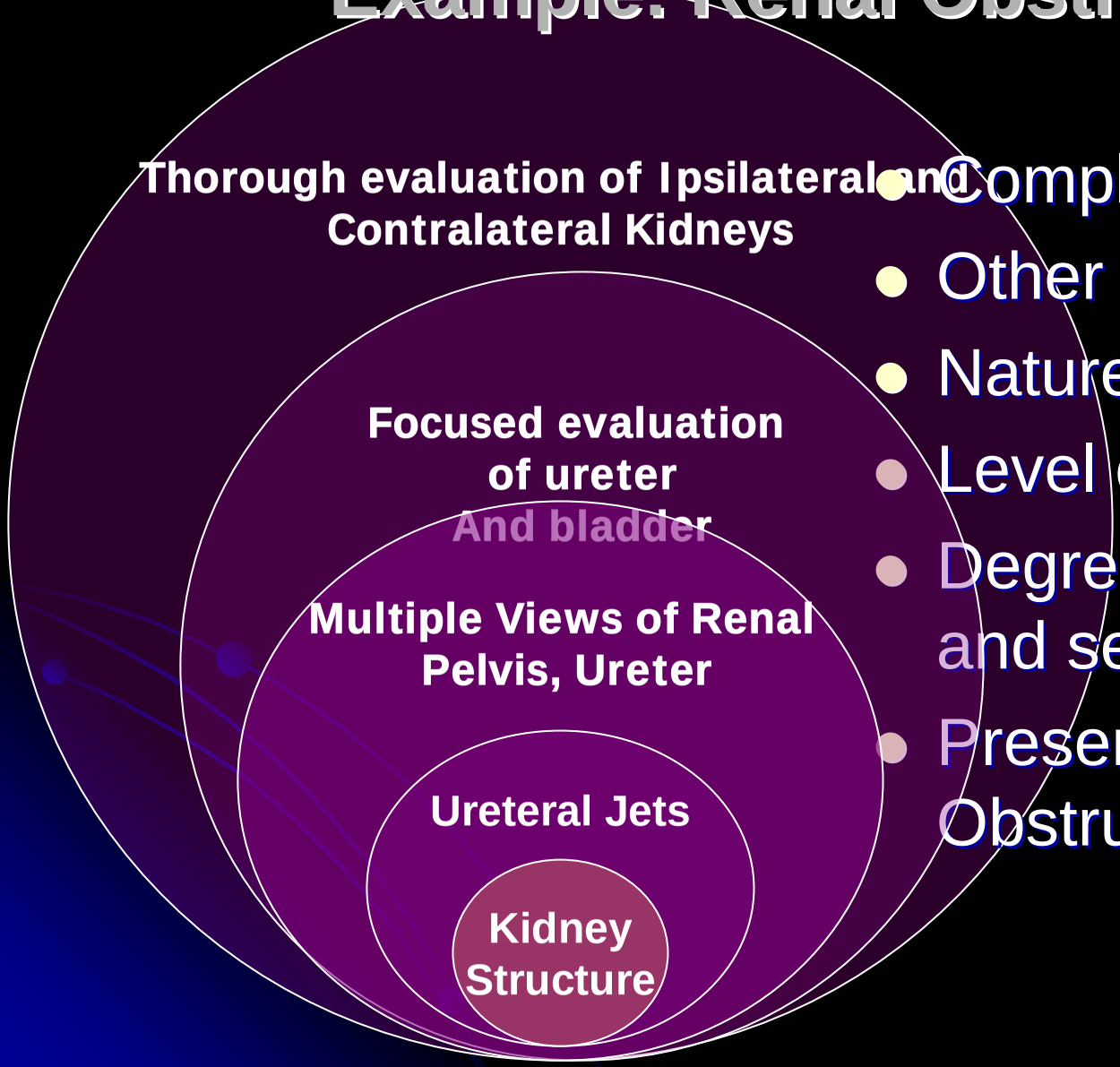
Focused Examination

Imaging follows a pre-defined and strictly prioritized sequence of clinical questions

Information obtained can be just one critical image or a full-fledged set of frames and video loops

Illustration on the next slide

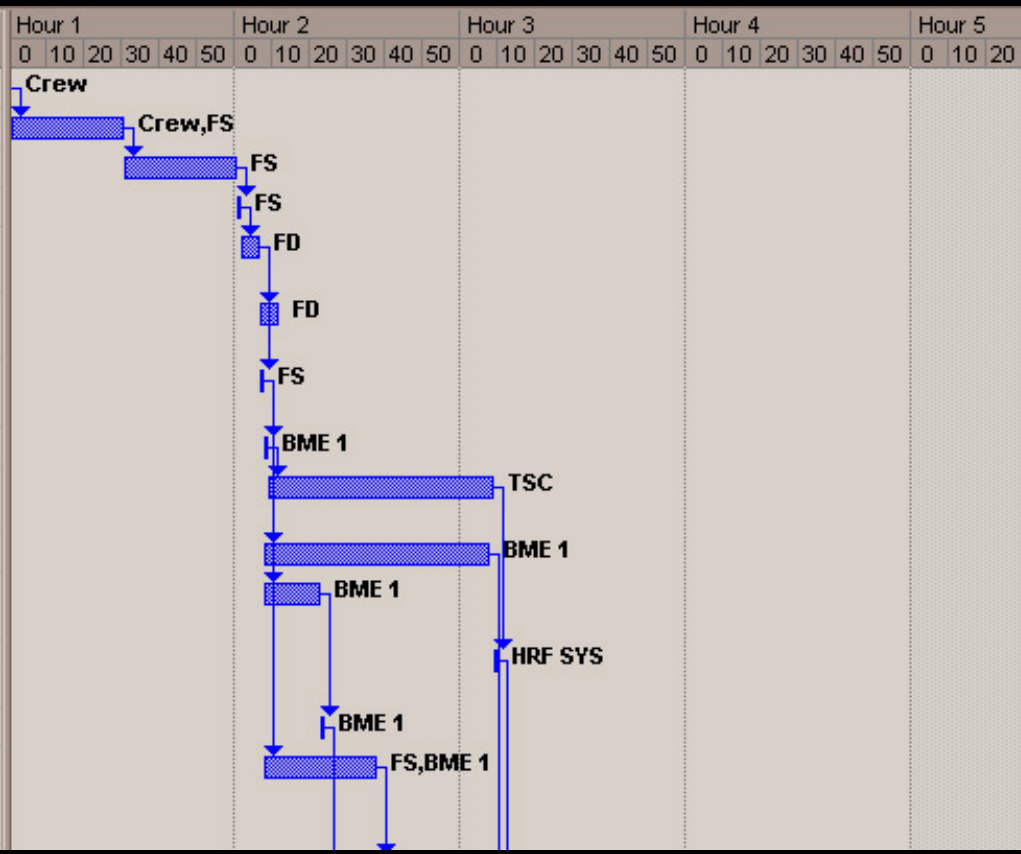
Example: Renal Obstruction



- Complete protocol
- Other stones?
- Nature of Obstruction
- Level of Obstruction
- Degree of Obstruction and secondary Signs
- Presence of Obstruction

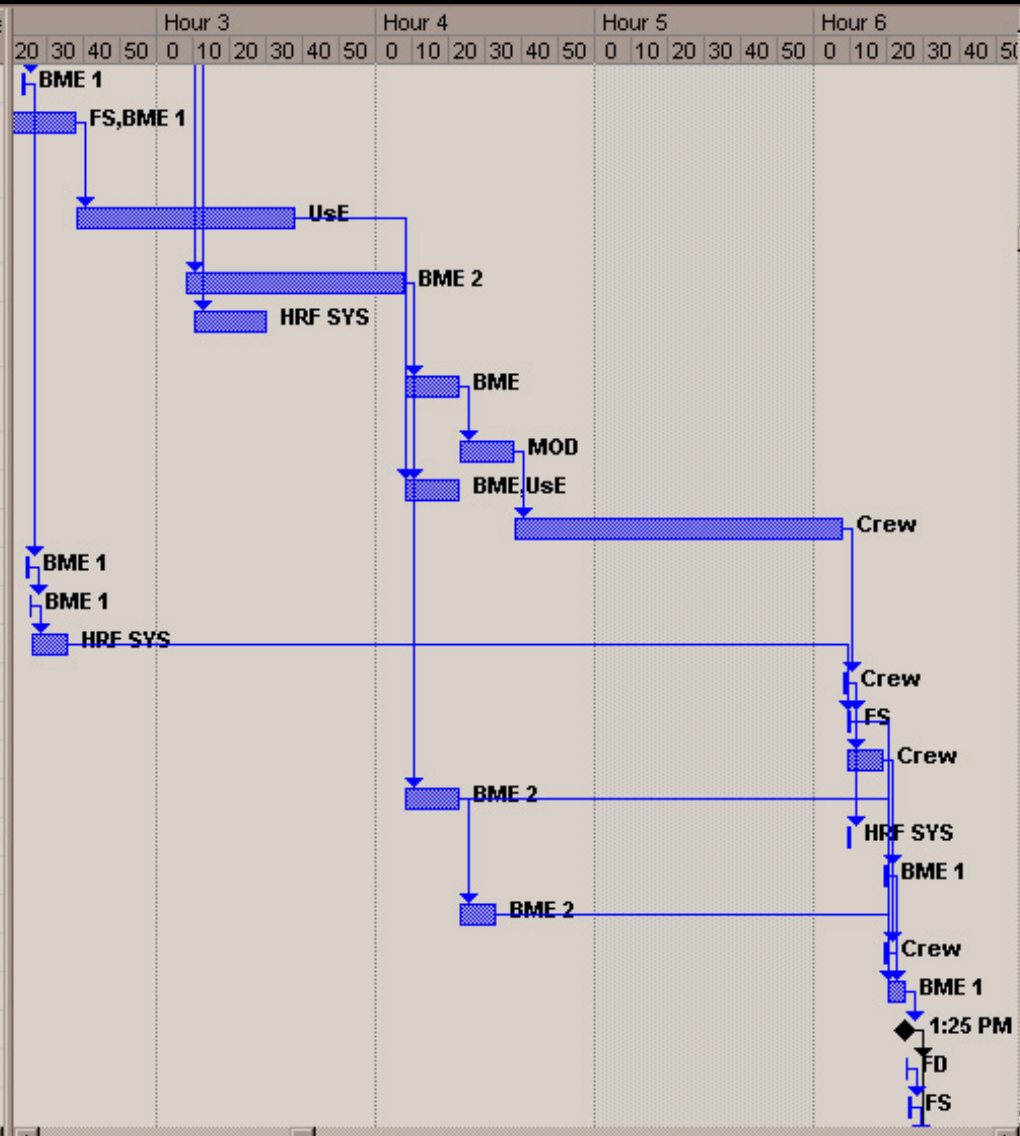
ISS Ultrasound Estimated Timeline - 1

	Task Name	Duration	Prede	Resource
1	CMO requests PMC with Flight Surgeon	1 min?		Crew
2	PMC Conducted	30 mins?	1	Crew,FS
3	FS determines Clinical Ultrasound is indicated	30 mins?	2	FS
4	FS ask FD for resources	1 min?	3	FS
5	FD grants permission for resources	5 mins?	4	FD
6	FD informs Flight Control Team of the situation and refers to FCOH #	5 mins?	5	FD
7	FS prescribes ultrasound and activates BME to prepare for contingency ultrasound	1 min?	5	FS
8	BME 1 calls TSC Ops on TSC loop to request supp	1 min?	7	BME 1
9	TSC telephones phone tree (HRF Systems, HRF Ultrasound, HRF Data Group) and request report	1 hr?	8	TSC
10	BME 1 calls in BME 2 for additional help	1 hr?	7	BME 1
11	BME 1 consults OSTPV, GC, Ops Plan to identify a time to conduct exam	15 mins?	7	BME 1
12	HRF Systems arrives at TSC and consults on MedOps loop with BME 1 on status of	1 min	9	HRF SYS
13	BME 1 informs FS, HRF SYS of planned timeline	1 min	11	BME 1
14	FS & BME 1 contact Ultrasound expert (UsE) to request report to MCC. Discuss history, exam required, probes and preparation necessary	30 mins	7	FS,BME 1



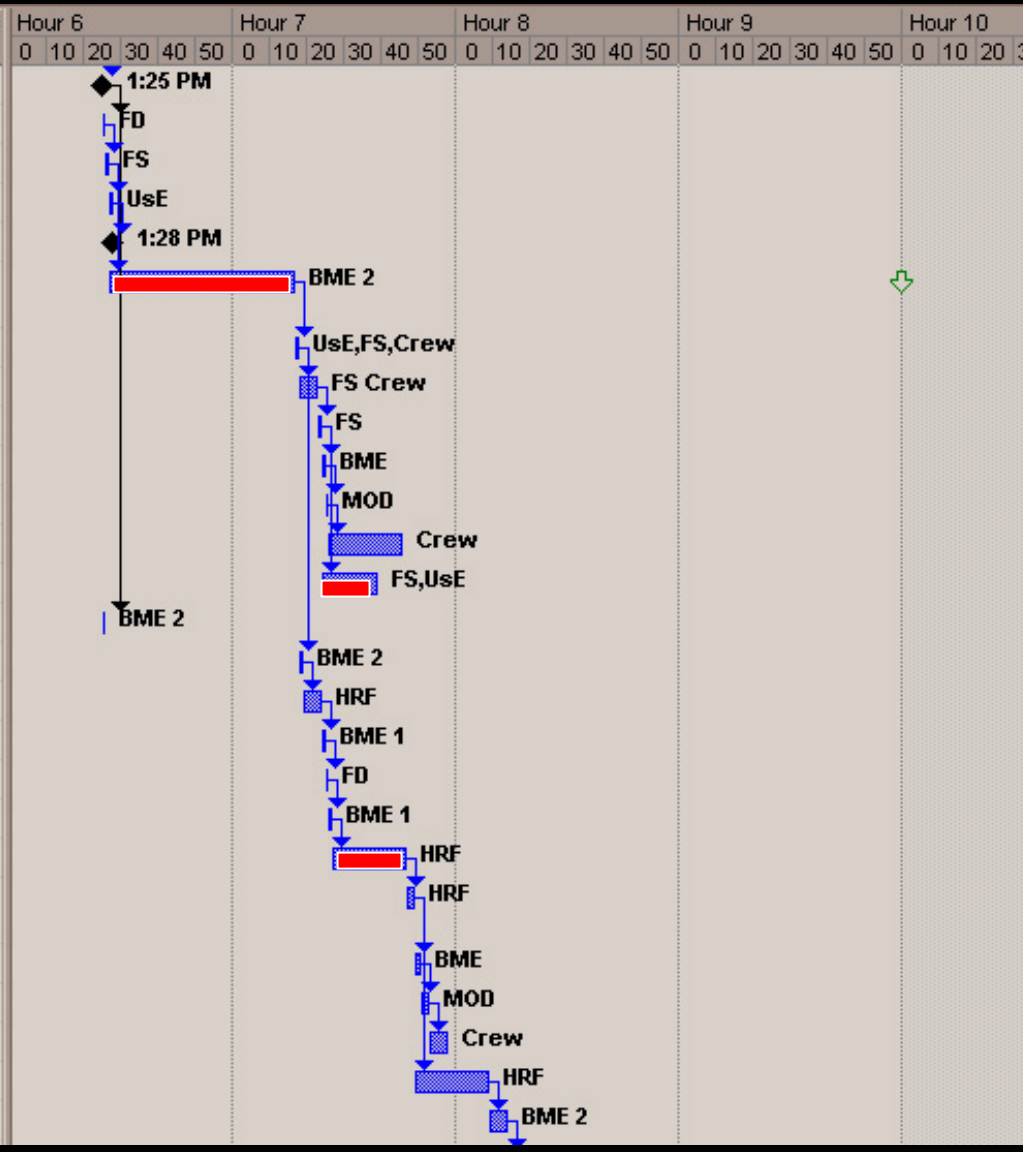
ISS Ultrasound Estimated Timeline - 2

	Task Name	Duration	Prede	Resource
13	BME 1 informs FS, HRF SYS of planned timeline	1 min	11	BME 1
14	FS & BME 1 contact Ultrasound expert (UsE) to request report to MCC. Discuss history, exam required, probes and preparation necessary	30 mins	7	FS,BME 1
15	UsE arrives at MCC	1 hr?	14	UsE
16	BME 2 Arrives	1 hr?	10	BME 2
17	HRF Sys prepares commands to configure HRF rack for ultrasound use	20 mins?	12	HRF SYS
18	BME 2 Provides procedures for hardware configuration to Flight	15 mins?	16	BME
19	Capcom calls procedures to crew	15 mins	18	MOD
20	BME2 confirms headset, monitor, cue cards with U	15 mins	16,15	BME,UsE
21	Crew begins HW setup	30 mins	19	Crew
22	BME1 request permission from FD to command rac	1 min	13	BME 1
23	BME 1 Give HRF Sys go to command rack	1 min	22	BME 1
24	HRF Sys command rack config and reports rack st	10 mins?	23	HRF SYS
25	Crew call FS for "go" for rack power up	1 min?	21	Crew
26	FS give crew go for power up and tells crew whi	1 min	25,24	FS
27	Crew completes Ultrasound set up and CMRS set	10 mins?	25	Crew
28	BME 2 coordinates private video and voice with G	15 mins?	16	BME 2
29	HRF Sys reports status of ultrasound to BME	1 min	25	HRF SYS
30	BME 1 confirms video displayed	1 min	27	BME 1
31	BME 2 confirms video and audio recording prepare	10 mins	28	BME 2
32	Crew calls FS ready to begin scanning	1 min	27	Crew
33	BME 1 Confirms all ready to go for Remote Guidan	5 mins?	32,31	BME 1
34	BME 1/FS request permission from FD to proceed	0 mins	33	FS,BME 1
35	FD approves to proceed	1 min	34	FD
36	FS calls crew on private S/G	1 min	35	FS



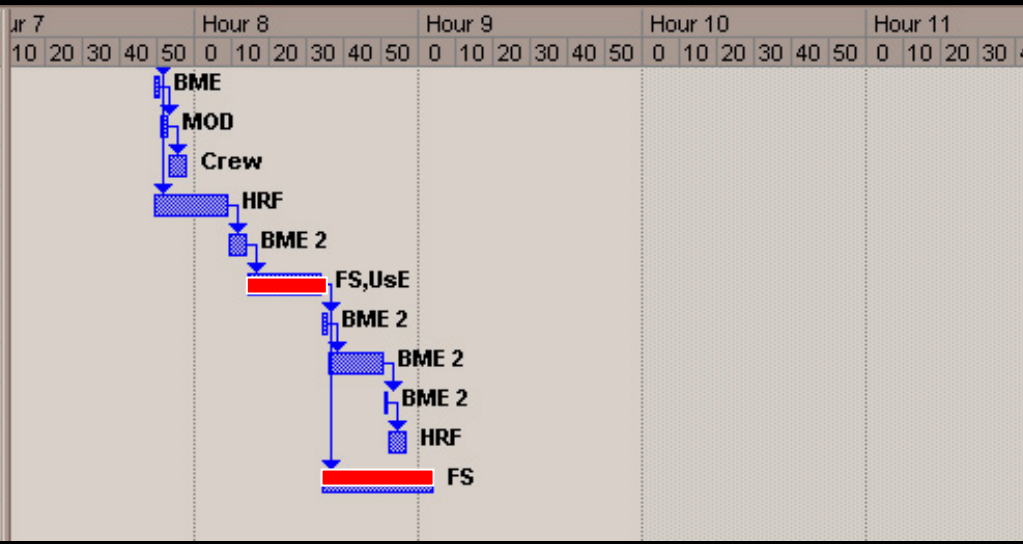
ISS Ultrasound Estimated Timeline - 3

	Task Name	Duration	Prede	Resource
34	BME 1/FS request permission from FD to proceed	0 mins	33	FS,BME 1
35	FD approves to proceed	1 min	34	FD
36	FS calls crew on private S/G	1 min	35	FS
37	FS hands com to UsE	1 min	36	UsE
38	UsE, FS, Crew conduct remotely guided ultrasoun	40 mins	37	UsE,FS,C
39	BME 2 provides com outage information and time hacks to FS and counts images and cine loops	50 mins	36	BME 2
40	UsE conlcludes ultrasound exam and hands com b	1 min	39	UsE,FS,C
41	FS complets PMC activites	5 mins	40	FS Crew
42	FS informs FD that PMC activities are complete	1 min	41	FS
43	BME informs flight of shut down procedures for cr	1 min	42	BME
44	Capcom communicates shutdown procedures to c	1 min	43	MOD
45	Crew performs shut down procedures	20 mins	44	Crew
46	FS and UsE conference on initial findings and dete	15 mins	42	FS,UsE
47	BME 2 informs HRF images will be captured and ne	1 min	34	BME 2
48	BME 2 informs HRF # of images to downlink	1 min	40	BME 2
49	HRF determines when images can be downlinked	5 mins	48	HRF
50	BME requests permission to downlink images	1 min	49	BME 1
51	FD grants permission	1 min	50	FD
52	BME 1 informs HRF go for downlink	1 min	51	BME 1
53	HRF downlinks images to TSC.	20 mins	52	HRF
54	HRF informs BME image downlink is complete and HRF laptop can be shutdown	2 mins	53	HRF
55	BME provides laptop shutdown procedures to Fligl	2 mins	54	BME
56	Capcom provides laptop shutdown procedures to	2 mins	55	MOD
57	Crew performs laptop shutdown procedures	5 mins	56	Crew
58	HRF burns images to CD and provides to BME	20 mins	54	HRF
59	BME 2 retrieves CD from TSC	5 mins	58	BME 2



ISS Ultrasound Estimated Timeline - 4

	Task Name	Duration	Prede	Resource
55	BME provides laptop shutdown procedures to Fligl	2 mins	54	BME
56	Capcom provides laptop shutdown procedures to	2 mins	55	MOD
57	Crew performs laptop shutdown procedures	5 mins	56	Crew
58	HRF burns images to CD and provides to BME	20 mins	54	HRF
59	BME 2 retrieves CD from TSC	5 mins	58	BME 2
60	FS and UsE review images and video in MCC	20 mins	59	FS,UsE
61	BME 2 confirms with FS and UsE video and images	2 mins	60	BME 2
62	BME 2 creates copy of video and images for reten	15 mins	61	BME 2
63	BME 2 informs HRF to delete images from TSC	1 min	62	BME 2
64	HRF confirms deletion of files to BME	5 mins	63	HRF
65	FS deterimines next steps, communicates to FD, B	30 mins	60	FS



Real-time Remote Guidance (Minimal Crew Autonomy)

Primary for Medical Operations:
Biomed MPSR (JSC Bldg. 30S)

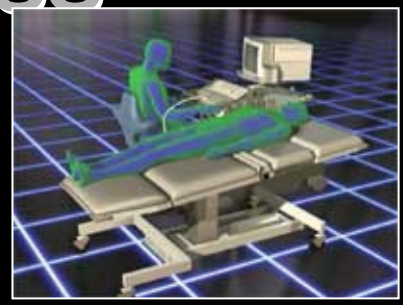
Alternative for Medical Operations:
Telescience Center (JSC Bldg. 30)

Computer-Assisted Freehand Ultrasound Imaging (Maximal Crew Autonomy)

- Protocol-Specific Just-in-time Training
- Loading Protocol-Specific Target Views and Images
- Loading Protocol-specific Computer Assistance Modules
- Data acquisition without ground control
- Transparent Data downlink
- Ground intervention if necessary and possible

Ultrasound Hardware - ISS

- Modified Philips/ATL 5000
- Part of Human Research Facility
- Arrived March 2001
- Hardware Tested on 10 Expeditions 2 -11
- Ultrasound sessions conducted on seven ISS Expeditions: 5 - 11



ISS ultrasound is the first high-definition permanent imaging capability in space

It may also be our last opportunity to answer many questions in space medicine and space physiology

Lunar Ultrasound System

- Imaging hardware
  - Highly Portable Ultrasound
  - Computer control
  - Computer guidance
  - Accessories
    - Gel, Wipes
    - Electrodes
- Space Comm Assets
  - Video downlink with variable compression
  - Standard duplex voice
- Ground Support Assets
  - Voice consoles
  - Video Monitors
  - Status monitoring from onsite computer programs
  - Recording capabilities

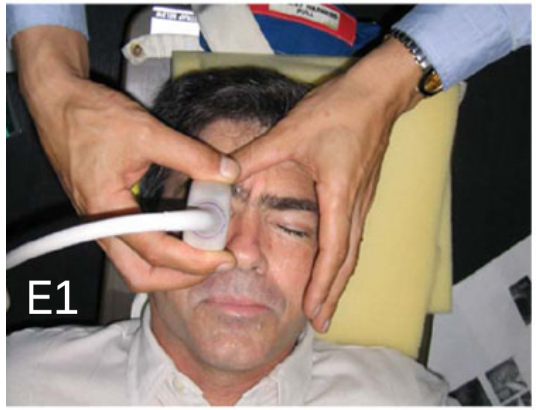
Ultrasound Hardware - Lunar

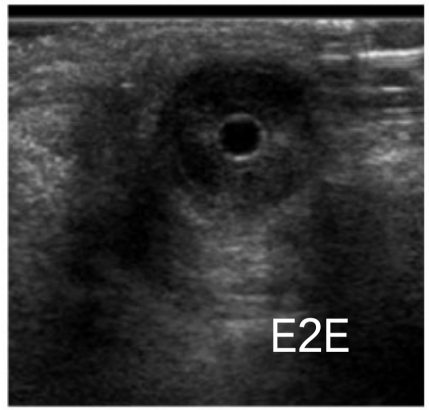
- Small, lightweight, possibly with control from a general purpose computer
- Feeding digital stream to an onboard video processing unit
- Low-power, maintenance-free, and unobtrusive

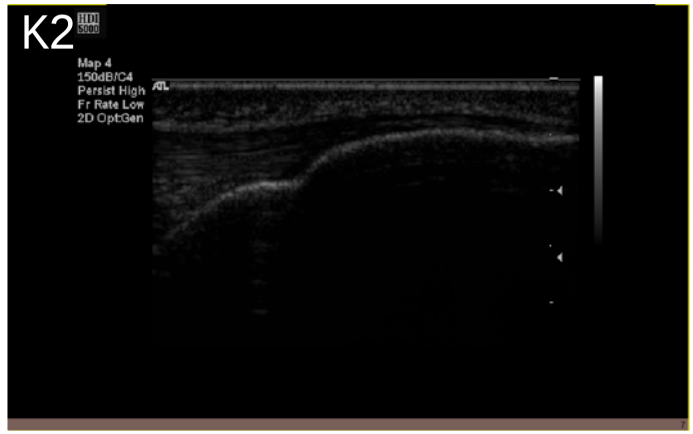
- Software on the onboard general purpose computer:
  - Just-In-Time training
  - Real-time video analysis for computer-assisted operator guidance
  - Data compression, storage, transmission
  - Relaying intervention from the ground

Payload Development Laboratory (PDL, NASA JSC Bldg. 9)

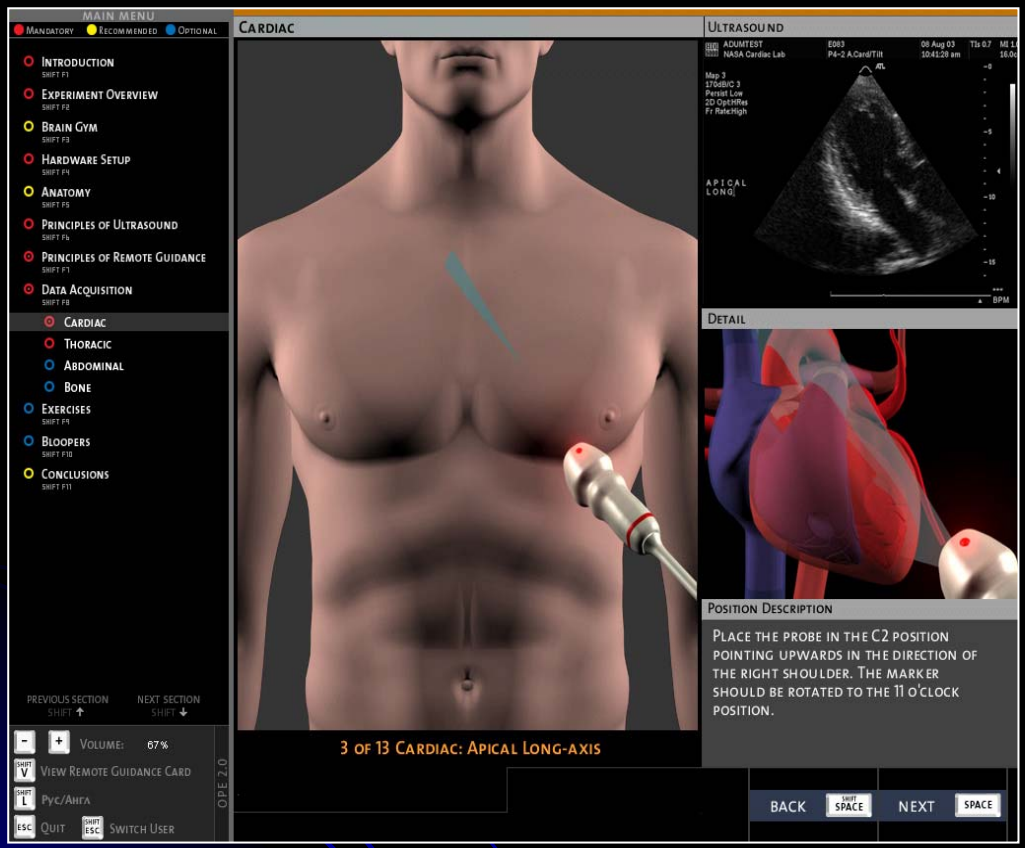
Reference Target Image sets and videos Procedure Video clips photos







Just-In-Time training



ISS and Lunar Techno-challenges

- Hardware set up– up to 45 min (ISS); c.15 min (L)
- Data transmission- 2s delay (ISS), 2-7s (L)
  - Simultaneous AV link- small blocks (20-50 min (ISS), continuous (L)
- Video
  - No Video Compression (ISS), variable (L)
  - Some degradation of video

Ultrasound Protocols Demonstrated in 0g

- Echocardiography
- Stress Echocardiography (limited)
- Thoracic: Hemo- and pneumothorax R/O
- Abdominal
  - Spleen, Liver, Biliary System, Pancreas
  - AA, IVC
- GU
  - Kidneys
  - Bladder
  - Prostate
  - GYN
- Musculoskeletal
  - Rotator Cuff
  - Knee, ankle, elbow, wrist, thoracic cage
- Thyroid
- Dental (limited)
- Sinus (limited)
- Eye
- Vasculature
  - Carotid/Jugular
  - Valsalva/Mueller Maneuvers
  - DVT R/O
- Other (e.g., peripheral nerves)

Reviewer Comments

"I reviewed all of the other images you sent. As you stated, they are all mildly blurry due to the capture process from videotape. If I ignore this degradation, I believe that all of the images are equal in quality to those we use everyday in our hospitals. We use two different types of units: (1) Philips HDI 5000 with the latest software, including XRES image processing and Sono-CT real-time compound imaging, and (2) Siemens Acuson Sequoia. ***The images you sent are equal in quality to what I see daily on the above units."***

Reviewer Comments

“The images you sent were all normal and I expect that you will have no trouble diagnosing disease when it arises. ”

Sample Application List for Ordering

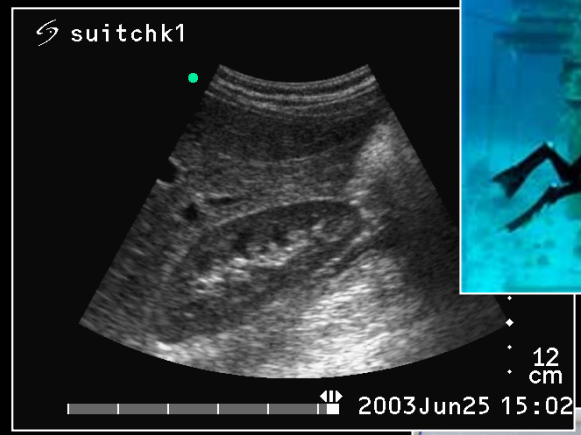
HEAD NECK AND FACE

APPLICATION TITLE	TYPE	NOTES / SCOPE	Done with remote guidnce ?	Performed on ISS?
Ophthalmic Sonography Complete	Complete (Standard)		Y	Y
Salivary Gland Sonography Complete	Complete (Standard)		Y	N
Thyroid Sonography Complete	Complete (Standard)		D	Y
Carotid Duplex Sonography Complete	Complete (Standard)		Y	D
Paranasal Sinus Sonography	Focused and Limited	Specify	Y	Y
Dental / oral Sonography	Focused and Limited	Extraoral, limited	Y	Y
Salivary Gland Sonography Ltd	Focused and Limited	Specify	Y	N
Ophthalmic Sonography - Limited	Focused and Limited	Unilateral or F/U	Y	Y
Ophthalmic Sonography - PLR	Focused and Limited	Pupillary Reflex	Y	D
Jugular Vein Sonography Specific	Focused and Limited	Specify Scope	Y	D
Image-Guided Vascular Access (Internal Jugular Vein)	Image-guided manipulations		N	N

Remote/Isolated locations

In this example (NEEMO):

- Engineer Operator
- Real-time guidance through Video Conferencing Unit ~364K
- Digital Images post exam (~1 hour)



Crew Medical Officer

In this example (Detroit Redwings):

- Operator – Athletic Trainer
- Real-time remote guidance through Internet connection - DSL
  - Internet videoconferencing
  - Raw data sent near-real-time to radiology
  - Review / manipulation of 3D raw data sets during and post examination

Physician On-site

In this example (South Pole):

- GP operator
- Monitoring of radial Fx healing

Methodology for Other medical Procedures
Example: Micro-Laparoscopy

CONCLUSIONS

- A wide array of ultrasound applications is available for the Surgeon to order on ISS
- Joint efforts of Space Medicine and HRF, enhanced by the ADUM experiment, provide strong methodology for:
  - Science uses of ISS ultrasound
  - Other space medical procedures
  - Development of medical systems for future missions
  - Substantial terrestrial applications

CONCLUSIONS - 2

- The ISS has allowed to clearly identify challenges of remote ultrasound and devise solutions to technical and procedural challenges
- Lunar ultrasound solutions are seen as a series of upgrades to the ISS ultrasound system, with the following common principles:
  - Minimally trained operator
  - Distributed expertise
  - Adaptive expertise delivery
  - Focused examinations with prioritized procedural sequences

Questions?