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

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Ashot E. Sargsyan MD; Jeffrey A. Jones, MD, Douglas R Hamilton, MD, PhD†; Scott A. Dulchavsky MD, PhD†,
J. Michael Duncan, MD
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?
Of the many imaging modalities, ultrasound has been the only one found suitable for use in low-Earth orbit.
# ISS Ultrasound Operations

<table>
<thead>
<tr>
<th></th>
<th>Hours of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MedOps / HRF</td>
<td>20</td>
</tr>
<tr>
<td>Research</td>
<td>85</td>
</tr>
<tr>
<td>Total</td>
<td>105</td>
</tr>
</tbody>
</table>
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

- Thorough evaluation of Ipsilateral and Contralateral Kidneys
- Complete protocol
  - Other stones?
  - Nature of Obstruction
  - Level of Obstruction
  - Degree of Obstruction and secondary Signs
  - Presence of Obstruction
- Focused evaluation of ureter and bladder
- Multiple Views of Renal Pelvis, Ureter
- Ureteral Jets
- Kidney Structure
ISS Ultrasound Estimated Timeline - 1

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Prede</th>
<th>Resource(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CMO requests PMC with Flight Surgeon</td>
<td>1 min?</td>
<td></td>
<td>Crew</td>
</tr>
<tr>
<td>2 PMC Conducted</td>
<td>30 mins?</td>
<td>1</td>
<td>Crew, FS</td>
</tr>
<tr>
<td>3 FS determines Clinical Ultrasound is indicated</td>
<td>30 mins?</td>
<td>2</td>
<td>FS</td>
</tr>
<tr>
<td>4 FS ask FD for resources</td>
<td>1 min?</td>
<td>3</td>
<td>FS</td>
</tr>
<tr>
<td>5 FD grants permission for resources</td>
<td>5 mins?</td>
<td>4</td>
<td>FD</td>
</tr>
<tr>
<td>6 FD informs Flight Control Team of the situation and refers to FCOH #</td>
<td>5 mins?</td>
<td>5</td>
<td>FD</td>
</tr>
<tr>
<td>7 FS prescribes ultrasound and activates BME to prepare for contingency ultrasound</td>
<td>1 min?</td>
<td>5</td>
<td>FS</td>
</tr>
<tr>
<td>8 BME 1 calls TSC Ops on TSC loop to request supp</td>
<td>1 min?</td>
<td>7</td>
<td>BME 1</td>
</tr>
<tr>
<td>9 TSC telephones phone tree (HRF Systems, HRF Ultrasound, HRF Data Group) and request report</td>
<td>1 hr?</td>
<td>8</td>
<td>TSC</td>
</tr>
<tr>
<td>10 BME 1 calls in BME 2 for additional help</td>
<td>1 hr?</td>
<td>7</td>
<td>BME 1</td>
</tr>
<tr>
<td>11 BME 1 consults OSTPV, GC, Ops Plan to identify a time to conduct exam</td>
<td>15 mins?</td>
<td>7</td>
<td>BME 1</td>
</tr>
<tr>
<td>12 HRF Systems arrives at TSC and consults on MedOps loop with BME 1 on status of</td>
<td>1 min</td>
<td>9</td>
<td>HRF SYS</td>
</tr>
<tr>
<td>13 BME 1 informs FS, HRF SYS of planned timeline</td>
<td>1 min</td>
<td>11</td>
<td>BME 1</td>
</tr>
<tr>
<td>14 FS &amp; BME 1 contact Ultrasound expert (UsE) to request report to MCC. Discuss history, exam required, probes and preparation necessary</td>
<td>30 mins</td>
<td>7</td>
<td>FS, BME 1</td>
</tr>
<tr>
<td>Task Name</td>
<td>Duration</td>
<td>Prede</td>
<td>Resource</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>----------</td>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>13 BME 1 informs FS, HRF SYS of planned timeline</td>
<td>1 min</td>
<td>11</td>
<td>BME 1</td>
</tr>
<tr>
<td>14 FS &amp; BME 1 contact Ultrasound expert (UsE) to request report to MCC. Discuss history, exam required, probes and preparation necessary</td>
<td>30 mins</td>
<td>7</td>
<td>FS, BME 1</td>
</tr>
<tr>
<td>15 UsE arrives at MCC</td>
<td>1 hr</td>
<td>14</td>
<td>UsE</td>
</tr>
<tr>
<td>16 BME 2 Arrives</td>
<td>1 hr</td>
<td>10</td>
<td>BME 2</td>
</tr>
<tr>
<td>17 HRF Sys prepares commands to configure HRF rack for ultrasound use</td>
<td>20 mins</td>
<td>12</td>
<td>HRF SYS</td>
</tr>
<tr>
<td>18 BME 2 Provides procedures for hardware configuration to Flight</td>
<td>15 mins</td>
<td>16</td>
<td>BME</td>
</tr>
<tr>
<td>19 Capcom calls procedures to crew</td>
<td>15 mins</td>
<td>18</td>
<td>MOD</td>
</tr>
<tr>
<td>20 Crew confirms headset, monitor, cue cards with L</td>
<td>15 mins</td>
<td>16,15</td>
<td>BME, UsE</td>
</tr>
<tr>
<td>21 Crew begins H/V setup</td>
<td>30 mins</td>
<td>19</td>
<td>Crew</td>
</tr>
<tr>
<td>22 BME1 request permission from FD to command rac</td>
<td>1 min</td>
<td>13</td>
<td>BME 1</td>
</tr>
<tr>
<td>23 BME 1 Give HRF Sys go to command rac</td>
<td>1 min</td>
<td>22</td>
<td>BME 1</td>
</tr>
<tr>
<td>24 HRF Sys command rac config and reports rac st</td>
<td>10 mins</td>
<td>23</td>
<td>HRF SYS</td>
</tr>
<tr>
<td>25 Crew call FS for &quot;go&quot; for rac power up</td>
<td>1 min</td>
<td>21</td>
<td>Crew</td>
</tr>
<tr>
<td>26 FS give crew go for power up and tells crew who</td>
<td>1 min</td>
<td>25,24</td>
<td>FS</td>
</tr>
<tr>
<td>27 Crew completes Ultrasound set up and CMRS set</td>
<td>10 mins</td>
<td>25</td>
<td>Crew</td>
</tr>
<tr>
<td>28 BME 2 coordinates private video and voice with Go</td>
<td>15 mins</td>
<td>16</td>
<td>BME 2</td>
</tr>
<tr>
<td>29 HRF Sys reports status of ultrasound to BME</td>
<td>1 min</td>
<td>25</td>
<td>HRF SYS</td>
</tr>
<tr>
<td>30 BME 1 confirms video displayed</td>
<td>1 min</td>
<td>27</td>
<td>BME 1</td>
</tr>
<tr>
<td>31 BME 2 confirms video and audio recording prepare</td>
<td>10 mins</td>
<td>28</td>
<td>BME 2</td>
</tr>
<tr>
<td>32 Crew calls FS ready to begin scanning</td>
<td>1 min</td>
<td>27</td>
<td>Crew</td>
</tr>
<tr>
<td>33 BME 1 confirms all ready to go for Remote Guidance</td>
<td>5 mins</td>
<td>32,31</td>
<td>BME 1</td>
</tr>
<tr>
<td>34 BME 1/FS request permission from FD to proceed</td>
<td>0 mins</td>
<td>33</td>
<td>FS, BME 1</td>
</tr>
<tr>
<td>35 FD approves to proceed</td>
<td>1 min</td>
<td>34</td>
<td>FD</td>
</tr>
<tr>
<td>36 FS calls crew on private S/G</td>
<td>1 min</td>
<td>35</td>
<td>FS</td>
</tr>
</tbody>
</table>
**ISS Ultrasound Estimated Timeline - 4**

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Prede</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>BME provides laptop shutdown procedures to Flight</td>
<td>2 mins</td>
<td>54</td>
<td>BME</td>
</tr>
<tr>
<td>Capcom provides laptop shutdown procedures to</td>
<td>2 mins</td>
<td>55</td>
<td>MOD</td>
</tr>
<tr>
<td>Crew performs laptop shutdown procedures</td>
<td>5 mins</td>
<td>56</td>
<td>Crew</td>
</tr>
<tr>
<td>HRF burns images to CD and provides to BME</td>
<td>20 mins</td>
<td>54</td>
<td>HRF</td>
</tr>
<tr>
<td>BME 2 retrieves CD from TSC</td>
<td>5 mins</td>
<td>58</td>
<td>BME 2</td>
</tr>
<tr>
<td>FS and Use review images and video in MCC</td>
<td>20 mins</td>
<td>59</td>
<td>FS,Use</td>
</tr>
<tr>
<td>BME 2 confirms with FS and Use video and images</td>
<td>2 mins</td>
<td>60</td>
<td>BME 2</td>
</tr>
<tr>
<td>BME 2 creates copy of video and images for reten</td>
<td>15 mins</td>
<td>61</td>
<td>BME 2</td>
</tr>
<tr>
<td>BME 2 informs HRF to delete images from TSC</td>
<td>1 min</td>
<td>62</td>
<td>BME 2</td>
</tr>
<tr>
<td>HRF confirms deletion of files to BME</td>
<td>5 mins</td>
<td>63</td>
<td>HRF</td>
</tr>
<tr>
<td>FS determines next steps, communicates to FD, B</td>
<td>30 mins</td>
<td>60</td>
<td>FS</td>
</tr>
</tbody>
</table>
Real-time Remote Guidance (Minimal Crew Autonomy)

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

Alternative for Medical Operations:
Telescence 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
Reference 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
- Musculoskeletal
  - Rotator Cuff
  - Knee, ankle, elbow, wrist, Thoracic cage
- Thyroid
- Dental (limited)
- Sinus (limited)
- Eye
- Vasculature
  - Carotid/Jugular
  - Valsalva/Mueller Maneuvers
- GU
  - AA, IVC
- Kidneys
- Bladder
- Prostate
- GYN
- Other (e.g., peripheral nerves)
“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.”
The images you sent were all normal and I expect that you will have no trouble diagnosing disease when it arises.
<table>
<thead>
<tr>
<th>APPLICATION TITLE</th>
<th>TYPE</th>
<th>NOTES / SCOPE</th>
<th>Done with remote guidance?</th>
<th>Perform ed on ISS?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ophthalmic Sonography Complete</td>
<td>Complete (Standard)</td>
<td></td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Salivary Gland Sonography Complete</td>
<td>Complete (Standard)</td>
<td></td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Thyroid Sonography Complete</td>
<td>Complete (Standard)</td>
<td></td>
<td>D</td>
<td>Y</td>
</tr>
<tr>
<td>Carotid Duplex Sonography Complete</td>
<td>Complete (Standard)</td>
<td></td>
<td>Y</td>
<td>D</td>
</tr>
<tr>
<td>Paranasal Sinus Sonography</td>
<td>Focused and Limited</td>
<td>Specify</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Dental / oral Sonography</td>
<td>Focused and Limited</td>
<td>Extraoral, limited</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Salivary Gland Sonography Ltd</td>
<td>Focused and Limited</td>
<td>Specify</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Ophthalmic Sonography - Limited</td>
<td>Focused and Limited</td>
<td>Unilateral or F/U</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Ophthalmic Sonography - PLR</td>
<td>Focused and Limited</td>
<td>Pupillary Reflex</td>
<td>Y</td>
<td>D</td>
</tr>
<tr>
<td>Jugular Vein Sonography Specific</td>
<td>Focused and Limited</td>
<td>Specify Scope</td>
<td>Y</td>
<td>D</td>
</tr>
<tr>
<td>Image-Guided Vascular Access (Internal Jugular Vein)</td>
<td>Image-guided manipulations</td>
<td></td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>
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?