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

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

Thorough evaluation of Ipsilateral and Contralateral Kidneys

Focused evaluation of ureter and bladder

Multiple Views of Renal Pelvis, Ureter

Ureteral Jets

Kidney Structure
<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Prede</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>BME 1 informs FS, HRF SYS of planned timeline</td>
<td>1 min</td>
<td>11</td>
<td>BME 1</td>
</tr>
<tr>
<td>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>UsE arrives at MCC</td>
<td>1 hr?</td>
<td>14</td>
<td>UsE</td>
</tr>
<tr>
<td>BME 2 Arrives</td>
<td>1 hr?</td>
<td>10</td>
<td>BME 2</td>
</tr>
<tr>
<td>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>BME 2 Provides procedures for hardware configuration to Flight</td>
<td>15 mins?</td>
<td>16</td>
<td>BME</td>
</tr>
<tr>
<td>Capcom calls procedures to crew</td>
<td>15 mins?</td>
<td>18</td>
<td>MOD</td>
</tr>
<tr>
<td>BME2 confirms headset, monitor, cue cards with L</td>
<td>15 mins?</td>
<td>16,15</td>
<td>BME, UsE</td>
</tr>
<tr>
<td>Crew begins H/W setup</td>
<td>30 mins?</td>
<td>19</td>
<td>Crew</td>
</tr>
<tr>
<td>BME1 request permission from FD to command rack</td>
<td>1 min?</td>
<td>13</td>
<td>BME 1</td>
</tr>
<tr>
<td>BME 1 Give HRF Sys go to command rack</td>
<td>1 min?</td>
<td>22</td>
<td>BME 1</td>
</tr>
<tr>
<td>HRF Sys command rack config and reports rack st</td>
<td>10 mins?</td>
<td>23</td>
<td>HRF SYS</td>
</tr>
<tr>
<td>Crew call FS for &quot;go&quot; for rack power up</td>
<td>1 min?</td>
<td>21</td>
<td>Crew</td>
</tr>
<tr>
<td>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>Crew completes Ultrasound set up and CMRS set</td>
<td>10 mins?</td>
<td>25</td>
<td>Crew</td>
</tr>
<tr>
<td>BME 2 coordinates private video and voice with Go</td>
<td>15 mins?</td>
<td>16</td>
<td>BME 2</td>
</tr>
<tr>
<td>HRF Sys reports status of ultrasound to BME</td>
<td>1 min?</td>
<td>25</td>
<td>HRF SYS</td>
</tr>
<tr>
<td>BME 1 confirms video displayed</td>
<td>1 min?</td>
<td>27</td>
<td>BME 1</td>
</tr>
<tr>
<td>BME 2 confirms video and audio recording prepare</td>
<td>10 mins?</td>
<td>28</td>
<td>BME 2</td>
</tr>
<tr>
<td>Crew calls Fs ready to begin scanning</td>
<td>1 min?</td>
<td>27</td>
<td>Crew</td>
</tr>
<tr>
<td>BME 1 Confirms all ready to go for Remote Guiding</td>
<td>5 mins?</td>
<td>32,31</td>
<td>BME 1</td>
</tr>
<tr>
<td>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>FD approves to proceed</td>
<td>1 min?</td>
<td>34</td>
<td>FD</td>
</tr>
<tr>
<td>FS calls crew on private S/G</td>
<td>1 min?</td>
<td>35</td>
<td>FS</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>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>FD approves to proceed</td>
<td>1 min</td>
<td>34</td>
<td>FD</td>
</tr>
<tr>
<td>FS calls crew on private SAG</td>
<td>1 min</td>
<td>35</td>
<td>FS</td>
</tr>
<tr>
<td>FS hands com to UsE</td>
<td>1 min</td>
<td>36</td>
<td>UsE</td>
</tr>
<tr>
<td>BME 2, FS, Crew conduct remotely guided ultrasound</td>
<td>40 mins</td>
<td>37</td>
<td>US, FS, C</td>
</tr>
<tr>
<td>BME 2 provides com outage information &amp; time</td>
<td>50 mins</td>
<td>38</td>
<td>BME 2</td>
</tr>
<tr>
<td>US concludes ultrasound exam and hands com to</td>
<td>1 min</td>
<td>39</td>
<td>US, FS, C</td>
</tr>
<tr>
<td>FS completes PMC activities</td>
<td>5 mins</td>
<td>40</td>
<td>FS, Crew</td>
</tr>
<tr>
<td>FS informs FD that PMC activities are complete</td>
<td>1 min</td>
<td>41</td>
<td>FS</td>
</tr>
<tr>
<td>BME informs flight of shut down procedures for cr</td>
<td>1 min</td>
<td>42</td>
<td>BME</td>
</tr>
<tr>
<td>Capcom communicates shutdown procedures to c</td>
<td>1 min</td>
<td>43</td>
<td>MOD</td>
</tr>
<tr>
<td>Crew performs shut down procedures</td>
<td>20 mins</td>
<td>44</td>
<td>Crew</td>
</tr>
<tr>
<td>FS and UsE conference on initial findings and dete</td>
<td>15 mins</td>
<td>45</td>
<td>FS, UsE</td>
</tr>
<tr>
<td>BME 2 informs HRF images will be captured and nr</td>
<td>1 min</td>
<td>46</td>
<td>BME 2</td>
</tr>
<tr>
<td>BME 2 informs HRF # of images to downlink</td>
<td>1 min</td>
<td>47</td>
<td>BME 2</td>
</tr>
<tr>
<td>HRF determines when images can be downlinked</td>
<td>5 mins</td>
<td>48</td>
<td>HRF</td>
</tr>
<tr>
<td>BME requests permission to downlink images</td>
<td>1 min</td>
<td>49</td>
<td>BME 1</td>
</tr>
<tr>
<td>FD grants permission</td>
<td>1 min</td>
<td>50</td>
<td>FD</td>
</tr>
<tr>
<td>BME 1 informs HRF go for downlink</td>
<td>1 min</td>
<td>51</td>
<td>BME 1</td>
</tr>
<tr>
<td>HRF downlinks images to TSC</td>
<td>20 mins</td>
<td>52</td>
<td>HRF</td>
</tr>
<tr>
<td>HRF informs BME image downlink is complete and HRF laptop can be shutdown</td>
<td>2 mins</td>
<td>53</td>
<td>HRF</td>
</tr>
<tr>
<td>BME provides laptop shutdown procedures to Fligi</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>57</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>
</tbody>
</table>
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)

- Ground intervention if necessary and possible
- Transparent Data downlink
- Data acquisition without ground control
- Modules
  - Loading Protocol-Specific Computer Assistance
  - Loading Protocol-Specific Target Views and Images
  - Protocols-Specific just-in-time Training
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)
- Video: 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

- Musculoskeletal:
  - Rotator Cuff
  - Knee, ankle, elbow, wrist, thoracic cage

- Thyroid
- Dental (limited)
- Sinus (limited)
- Eye
- Vascular:
  - Carotid/Jugular
  - Valsalva/Mueller Maneuvers
  - DVT R/O

- Other (e.g., peripheral nerves)
- GU
  - Kidneys
  - Bladder
  - Prostate
  - GYN
- Musculoskeletal:
  - Rotator Cuff
  - Knee, ankle, elbow, wrist, thoracic cage
“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.”
## Sample Application List for Ordering

### HEAD NECK AND FACE

<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</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)
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?