

## AEROSPACE MEDICINE CLERKSHIP ROTATION SUMMARY

### SMART ULTRASOUND REMOTE GUIDANCE EXPERIMENT (SURGE) PRELIMINARY FINDINGS

#### PRECEPTORS

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#### INTRODUCTION

To date, diagnostic quality ultrasound images were obtained aboard the International Space Station (ISS) using the ultrasound of the Human Research Facility (HRF) rack in the Laboratory module. Through the Advanced Diagnostic Ultrasound in Microgravity (ADUM) and the Braslet-M Occlusion Cuffs (BRASLET SDTO) studies, non-expert ultrasound operators aboard the ISS have performed cardiac, thoracic, abdominal, vascular, ocular, and musculoskeletal ultrasound assessments using remote guidance from ground-based ultrasound experts.

With exploration class missions to the lunar and Martian surfaces on the horizon, crew medical officers will necessarily need to operate with greater autonomy given communication delays (round trip times of up to 5 seconds for the Moon and 90 minutes for Mars) and longer periods of communication blackouts (due to orbital constraints of communication assets). The SURGE project explored the feasibility and training requirements of having non-expert ultrasound operators perform autonomous ultrasound assessments in a simulated exploration mission outpost. The project aimed to identify experience, training, and human factors requirements for crew medical officers to perform autonomous ultrasonography.

All of these aims pertained to the following risks from the NASA Bioastronautics Road Map:

- Risk 18: Major Illness and Trauma
- Risk 20: Ambulatory Care
- Risk 22: Medical Informatics, Technologies, and Support Systems
- Risk 23: Medical Skill Training and Maintenance

#### METHODS

SURGE explored the use of a “just-in-time” computer-based learning tool, called the Onboard Proficiency Enhancer Light (OPEL) as an aid to a hypothetical crew medical officer working autonomously. Subjects were randomized into one of three groups. Each subject received standardized training before the experiment. The experiment consisted of two parts: 1) Ultrasound fracture assessment; and, 2) Focused Assessment with Sonography in Trauma (FAST) assessment of a simulated patient’s abdomen. A post-experiment questionnaire was completed by the subjects.

#### SUBJECTS

Subjects were selected from available medical and non-medical staff associated with Wyle and the NASA Space Medicine group. Exclusion criteria included having taken a formal ultrasound course or having completed more than two hours of hands-on ultrasound use. From the twenty-two (22) subjects, six (6) had more than three years of medical school training with one of the six being a physician astronaut.

#### RANDOMIZED GROUPS

The subjects were randomized into three groups for the entirety of the experiment.

- **Group A – Remote Guidance:** subjects had access to an expert ultrasound remote guider (radiologist or emergency medicine physician with FAST ultrasound certification). There was a 5-second round-trip communication delay in both the audio and video communication between the

subject and the remote guider. The remote guider had a video link from the ultrasound machine but no other cabin views of subject. Additionally, the subjects had an *Ultrasound Cue Card* affixed next to the ultrasound screen.

- **Group B – Autonomous operation with OPEL:** subjects had access to the computer-based training tool, OPEL, to review techniques and guidance before performing the ultrasound assessment. Additionally, the subjects had an *Ultrasound Cue Card* affixed next to the ultrasound screen.
- **Group C – Remote Guidance with OPEL:** subjects had access to the same resources as Group A with additional access to the computer-based training tool, OPEL. Additionally, the subjects had an *Ultrasound Cue Card* affixed next to the ultrasound screen.

#### ON-BOARD PROFICIENCY ENHANCER LIGHT (OPEL)

The OPEL system comprised of a multimedia presentation including a line-by-line written procedural description, reference ultrasound images, and an illustrative video of the procedure to follow to complete a given ultrasound scan. OPEL was separated into two parts, one for each of the parts of the experiment. The duration of the videos were 2 minutes and 32 seconds for the fracture assessment and 1 minute and 0 seconds for the FAST abdomen assessment. The following figures illustrate the OPEL system.

#### ULTRASOUND – LIMB FRACTURE (ISS MED/3A - ALL/FIN 1) Page 1 of 2 pages

##### Symptoms

Pain  
Discomfort  
Diminished usability of limb

##### Signs

Swelling  
Deformity  
Breaks in skin (possible open fracture)  
Diminished range of motion in joints

##### Diagnosis

1. Prepare **RIGHT** limb for ultrasound by placing a line of gel from the top to the bottom of the limb
2. Place ultrasound probe in longitudinal view (parallel to line drawn from patient's head to feet, see figures 1&2) with probe marker towards the patient's head at the top of the limb (closest to patient's head)
3. Identify the white bone surface
4. Adjust depth so that the white bone surface is in the middle of the screen
5. Adjust gain as necessary to improve image quality
6. Scan the length of the bone by slowly sliding the probe towards the patient's feet
7. Identify any areas of interest that may represent a fracture (see reference image C)
8. For each area of interest identified
  - a. Freeze and acquire an image of injured area in the longitudinal view
  - b. Rotate the probe 90 degrees counter-clockwise and freeze and acquire an image of injured area in the transverse view
9. If no area of interest is identified, please freeze and acquire a representative image in each of the longitudinal view and transverse view
10. Repeat steps 1-9 for the **LEFT** limb

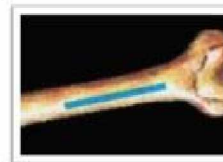


Figure 1 Correct probe orientation



Figure 2 Incorrect probe orientation



Figure 1. OPEL fracture assessment. The actual procedure is at the top. An example of the procedure being executed is seen in the lower left while a video of what is being seen through the ultrasound probe is on the right.

#### Probe Position 1 – Patient's RIGHT Side

1. Have patient raise his right hand above his head
2. Apply ultrasound gel to the face of the probe and patient's area to be scanned
3. Place probe in A6 to A4 (refer to Cue Card) along patient's right side and maintain firm pressure
4. Ensure probe marker is towards patient's head
5. Identify interface between liver and kidney
6. Record a LOOP VIDEO of the interface while performing a SWEEP (tilting probe back and forth)
  - a. Press ACQUIRE (you have 10 seconds to perform the next two steps)
  - b. Tilt probe in one direction until kidney disappears from view
  - c. Tilt probe in other direction until kidney appears and then disappears again
  - d. Ultrasound machine automatically stops recording after 10 seconds and provides an aural "beep" to indicate the end of video recording
  - e. If complete interface was not acquired during the above SWEEP, repeat steps a-d
7. Remove gel from patient using a paper towel and have patient lower his arm

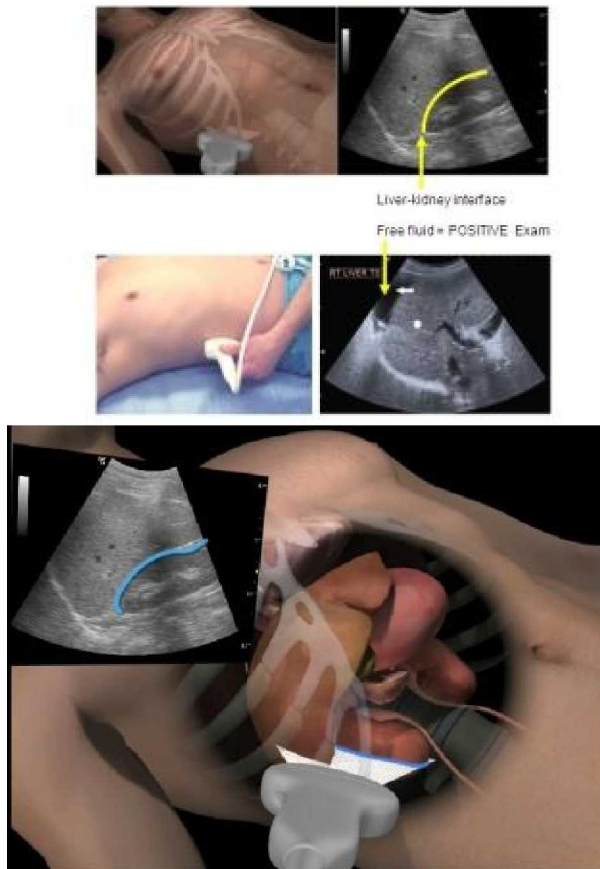


Figure 2. OPEL FAST abdomen assessment. The actual procedure is at the top. An computer generated example of the procedure being executed is seen below the procedure with the inset picture showing video of what is being seen through the ultrasound probe.

#### Pre-experiment training

All of the subjects received a standardized 10-minute training session that included ultrasound familiarization, principles of image generation, probe orientation conventions, use of ultrasound interface,

and communicating with a time delay. If time permitted, subjects were introduced to ultrasound use on a living person by scanning either a thyroid or an antecubital fossa.

#### EXPERIMENT TASKS

The experiment was divided into two parts. The first part tasked the subject to complete an ultrasound assessment of two phantom limbs to determine if a bone fracture was present in either of the two limbs. Subjects of group A (remote guidance) were guided through the assessment by the remote guider operating through a 5-second communication delay. Subjects of group B (autonomous operation with OPEL) reviewed OPEL's video and written procedure prior to initiating their assessment. Subjects of C (remote guidance and OPEL) were instructed to review the video component of OPEL and then given the option of reviewing the written procedure or proceeding with the remote guider providing guidance through the procedure. All subjects were presented with phantom limbs that had a fracture of the right limb, but no fracture of the left limb. Task completion time was recorded and four ultrasound images, a longitudinal and a transverse view of each limb (at the site of fracture, if applicable), were stored for later review. Additionally, the subject was asked to record whether or not each limb was fractured and the confidence of their diagnosis.

The second part of the experiment tasked the subject to complete a FAST abdomen ultrasound assessment of a simulated patient. The experiment used three different simulated patients all holding NASA Human Test Subject certification. In an identical manner to part one, subjects reviewed OPEL and/or had remote guidance depending upon their experiment group. None of the simulated patients had free fluid within their abdomen and all were asked not to void before the experiment to improve ultrasound visibility of their bladder. Task completion time was recorded and four ultrasound images, right-upper-quadrant hepatorenal interface view, left-upper-quadrant splenorenal interface view, suprapubic bladder view, and a sub-xyphoid



pericardial view, were stored for later review. Subjects were not asked to interpret the ultrasound images.

The images from each of the two parts of the experiment were reviewed by a non-blinded, FAST certified, family physician and provided with an image quality rating. Each of the four views for each part of the experiment was provided a rating of either 0 meaning “non-diagnostic” or 1 meaning “diagnostic”. The overall image quality for a particular part of the experiment was formed by summing the ratings for each of the four views such that the ratings ranged from 0 to 4.

#### POST-EXPERIMENT QUESTIONNAIRE.

All subjects completed a 22-question questionnaire that assessed the subjects’ perceived effectiveness of the pre-experiment training, the cue card, the OPEL computer-based training, and the remote guidance. Furthermore, the questionnaire specifically assessed the subjects’ perceived level of difficulty and frustration in completing the two experimental tasks.

### FINDINGS

The results are presented in three sections with the first two corresponding to the respective two parts of the experiment and the third corresponding to the results of the post-experiment questionnaire. An analysis of variance (ANOVA) with Tukey’s Honestly Significant Difference (HSD) test was used to compare the three groups. This test controlled for the multiple comparisons and provided a pairwise comparison of groups.

#### PART 1: FRACTURE ASSESSMENT

The fractured limb was correctly identified by 100% of the subjects in the *Remote guidance with OPEL* group, 86% of the subjects in the *Remote guidance* group, and 88% of the subjects in the *Autonomous with OPEL* group. The differences were not significant. Please refer to figure 3. There was no significant difference between group’s diagnostic confidences ( $p=0.52$ ) with the *Remote guidance*,

*Autonomous with OPEL*, and *Remote guidance with OPEL* groups having respective mean confidences of 96.3%, 91.3%, and 91.3%.

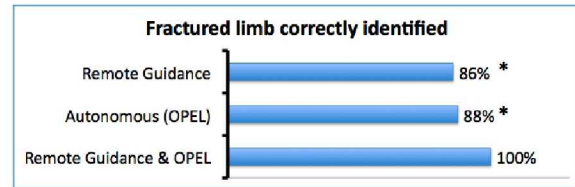


Figure 3. Part 1 mean accuracy in identification of fractured limb.

Task completion times for the fracture assessment were significantly longer for the *Remote guidance with OPEL* group, mean of 11.2 minutes (min), as compared to the *Remote guidance* group, mean of 8.4 min, with a mean difference of 2.8 min [0.6-5.0, 95% confidence interval] and  $p=0.01$ . There was no other pairwise significant difference between groups for task completion time. The mean task completion time for the *Autonomous with OPEL* group was 9.8 min.

Image quality was significantly better for both the *Remote guidance* and the *Remote guidance with OPEL* groups, each with a mean of 4.0/4.0 as compared to the *Autonomous with OPEL* group, mean of 2.6/4.0 ( $p=0.00$ ). The mean difference between the *Autonomous with OPEL* group and each of the *Remote guidance* and *Remote guidance with OPEL* groups was 1.4 min [0.5 - 2.2]. Please refer to figure 4.

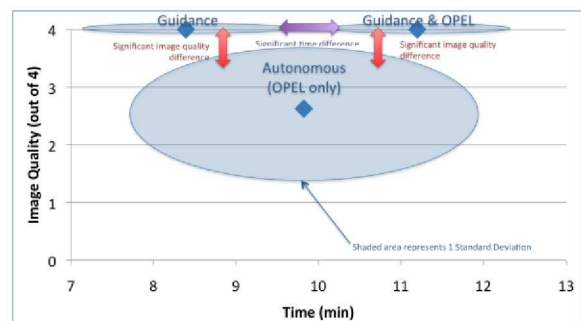


Figure 4. Part 1: fracture assessment task completion times, image quality, standard deviations, and significant differences.

**PART 2: FAST ABDOMEN ASSESSMENT**

For the second part of the experiment, FAST abdomen assessment, the standard deviations for both task completion time and image quality were greater than for the first part of the experiment. As such, the only significant difference was in the image quality between the *Remote guidance with OPEL*, mean of 3.1/4.0, compared to the *Autonomous with OPEL* group, mean of 1.6/4.0 ( $p=0.03$ ). The mean difference was 1.5 min [0.1 – 2.9]. The *Remote guidance* group mean image quality was 2.9. Of all groups, subjects with previous medical training obtained a significantly higher image quality, mean of 3.3/4.0, compared to those without medical training, mean of 2.2/4.0 ( $p=0.05$ ). Please refer to figure 6. The mean task completion times were 21.1 min for the *Remote guidance* group, 21.2 min for the *Autonomous with OPEL* group, and 23.5 min for the *Remote guidance with OPEL* group. Please refer to figure 5.

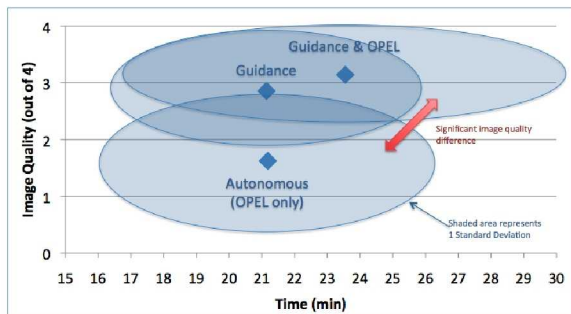


Figure 5. Part 2: FAST abdomen assessment task completion times, image quality, standard deviations, and significant differences.



Figure 6. Comparison of FAST image quality between medically trained vs. non-medically trained subjects.

**POST-EXPERIMENT QUESTIONNAIRE**

Finally, an examination of the results of the post-experiment questionnaire revealed that there were no questions with statistically significant differences across the three groups. There was a trend towards those in the *Autonomous with OPEL* group finding the experiment more difficult and more frustrating as compared to the other two groups. Please refer to figures 7 and 8.

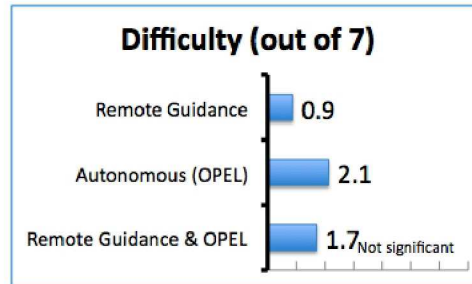


Figure 7. Difficulty rating on post-experiment questionnaire with 1 being “Not difficult at all” and 7 being “Very difficult”.

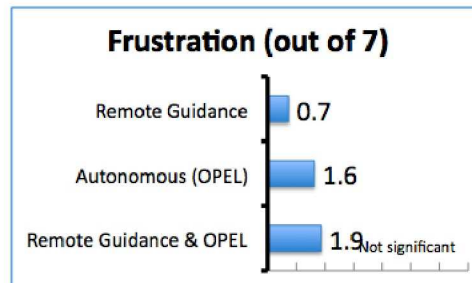


Figure 8. Frustration rating on post-experiment questionnaire with 1 being “Not frustrated at all” and 7 being “Completely frustrated”.

Key qualitative suggestions for improvement included the following:

Overall task

- Maintain consistent plain language
- Reinforce firmer pressure to improve image quality

Pre-experiment training

- Include a “tour” through the human body showing appearance of specific organs

#### Cue-card

- Add instructions on how to capture a STILL and a VIDEO LOOP
- Include a description of "SWEEP" = tilting probe one way and then the other to visualize an organ or interface
- Change position of A4 to be more posterior in mid-axillary line

#### Remote guidance

- Limit instructions to 3 steps so as to not get ahead of ultrasound operator
- Provide positive feedback when proper images obtained to aid ultrasound operator confidence
- Share with ultrasound operator what a "positive" scan would show

#### FAST abdomen procedure

- Remove medical language
- Better describe orientation of probe and include pictures of orientation
- Better describe how to locate the kidney
- Describe how to manage with rib shadows
- Better describe procedure to visualize heart from sub-xyphoid approach
- Reset depth setting after each position to avoid missing far-field structures
- Include a "problem-solving" section that describes potential maneuvers to attempt to gain the desired image
- Embed videos in word document at relevant line items

#### FAST abdomen video

- Remove medical language
- Expand video to include more still pictures of the desired views with labels describing the target organs and where "free fluid" would appear
- Better describe how to do a SWEEP or "tilt" to visualize an interface
- Emphasize need to have probe nearly parallel with abdomen and tucked under ribs with firm pressure to visualize heart

- Provide examples of "positive" free fluid ultrasound images in video
- Include a "problem-solving" section that describes potential maneuvers to attempt to gain the desired image (i.e. breath holds, bending knees, rotating probe, panning probe)

## DISCUSSION

With no more than ten (10) minutes of ultrasound training, all subjects were able to use the ultrasound to obtain relevant images. This speaks to the benefits of a focused teaching session and to the intrinsic ability of humans to adapt to new situations. As was expected, those with previous medical training, and by virtue of this training greater anatomy knowledge, produced better quality images.

For both the fracture assessment and the FAST abdomen assessment, subjects with remote guidance produced better quality images than those operating autonomously. This was primarily due to near-instant feedback on the quality of images provided by the remote guider. As the communication time delay expands, the capability to provide this feedback greatly diminishes. As such, successful autonomous ultrasound operation becomes a greater necessity.

Subjects provided feedback that they would have preferred more reference images placed directly next to their ultrasound screen so as to provide a degree of quality feedback through the subjects' own pattern-recognition capabilities. Subjects theorized that by having a tool that advanced through the ultrasound assessment in a stepwise manner and presented relevant images and technique aids to obtain these images, they would have better captured the images necessary to achieve higher image quality in the study.

Interestingly, subjects of the *autonomous with OPEL* group rated the task as being neither more difficult

nor more frustrating than those with remote guidance.

## NEXT STEPS

Much has been learned in the first phase of the SURGE project. By implementing both the suggestions obtained from subjects and observed areas for augmentation obtained from experimenters, the OPEL product will be substantially improved. Further testing of the autonomous operation of ultrasound with the assistance of OPEL in the microgravity environment is the next step. Patient restraint systems, ultrasound operator restraint systems, ultrasound operator stress management, workstation set-up and securing, and gel containment are but some of the issues to be addressed for successful completion of autonomous ultrasound in a microgravity environment.

## CONCLUSION

Remote guidance continues to produce higher quality ultrasound images than autonomous ultrasound operation. The OPEL has potential to provide an excellent training and coaching tool for both remotely guided and autonomous operation. With the implementation of some of the many suggestions for improvement obtained during the experiment OPEL has potential to become an essential component of future exploration class medical operations.

## ACKNOWLEDGEMENTS

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