Just-in-time Training with Remote Guidance for Ultrasound-Guided Percutaneous Intervention

David J. Lerner; Michael S. Pohlen; Robert C. Apland; Sherveen N. Parivash

BACKGROUND: Management of surgical emergencies in spaceflight will pose a challenge as the era of exploration class missions dawns, requiring increased crew autonomy at a time when training and supplies will be limited. Ultrasound-guided percutaneous intervention would allow for the management of a variety of pathologies with largely shared equipment and training. This proof-of-concept work attempts to determine the feasibility of "just-in-time" remote teaching and guidance of a sample procedure of this type.

METHODS: Subjects naïve to ultrasound-guided intervention were instructed via a short video regarding the technique for placement of a percutaneous drain into a simulated abscess within a gel phantom. Subjects were then guided through the performance of the procedure via two-way audiovisual communication with an experienced remote assistant. Technical success was determined by the successful aspiration or expression of fluid from the simulated abscess following drain placement. This was then performed by and compared with staff experienced with such procedures. Time to completion and number of needle redirections required were also measured.

RESULTS: All 29 subjects naïve to interventional work and the 4 experienced control subjects achieved technical success. There was a statistically significant difference in the time to completion between the two groups, with the experienced subjects averaging 2 min to completion and the inexperienced 5.8 min. There was no statistically significant difference in the number of redirections.

DISCUSSION: This proof-of-concept work demonstrates high rates of technical success of percutaneous ultrasound-guided intervention in previously inexperienced personnel when provided with brief just-in-time training and live two-way audiovisual guidance.

KEYWORDS: aerospace medicine, ultrasound-guided procedure, radiology training.

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Ultrasound has a long and established history of use in spaceflight for medical diagnostics and monitoring, both aboard the International Space Station (ISS) and its predecessors.[1,4] The imaging modality has been implemented for evaluation of pathology ranging from optic globe flattening to venous thrombosis to renal calculi. As point-of-care ultrasound is an inherently operator dependent technique and there are limitations to crewmember training time, just-in-time inflight training has been combined with real-time guidance to enable the performance of this wide range of exams.[3] These efforts have met with success, with acceptable accuracy, consistency, and speed, despite nonphysician operators. These results are further supported by multiple terrestrial studies demonstrating effective teleguidance of ultrasound-naïve trainees for cardiopulmonary and trauma evaluation.[6,12] Entering the era of exploration class missions, with increasing difficulty of medical evacuation but similar limits on preflight training and crew size, onboard educational tools and real-time or near real-time ground-based guidance will prove increasingly vital for the continued utility of complex ultrasound evaluations.

From the University of Washington, Seattle, WA, and Stanford University, Stanford, CA, USA.

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Address correspondence to: Michael S. Pohlen, M.D., Dept. of Radiology, Stanford University School of Medicine, 1 Maple St., #1404, Redwood City, CA 94063; m.pohlen@gmail.com.

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Management of surgical conditions in spaceflight presents numerous challenges given the resource constraints, reduced gravity, and unique pathology encountered in this environment.[2] While a surgical emergency has yet to transpire in spaceflight, data from probabilistic risk assessments based partially on analog populations suggest that medical events are more likely to occur as mission length and crew size increase.[1] Given that prophylactic surgery is unlikely to reduce mission risk, surgical techniques targeted toward these and other pathology have and will continue to be developed and adapted for use in spaceflight.[13]

Difficult resource trade-offs are encountered when dedicating personnel, training, and equipment to the task of providing inflight care for surgical pathology. Specific concerns include mass, power, and space limitations of medical and surgical equipment, technical skill to perform the procedure in microgravity with limited instrumentation, and postsurgical care including management of any potential complications. Ultrasound-guided intervention is one potential aid to many potential surgical emergencies.[11,14] Portable ultrasound probes and interventional equipment are lightweight and compact, the necessary incisions small, the recovery time short, and the complications less frequent than following open surgery. While the need has not yet arisen to perform imaging-guided interventions on the ISS, there have not been any physicians to date with formal training in interventional radiology in the astronaut program, and even in the case of formal training, skills may atrophy before their need arises. Future exploration class lunar and Martian missions may require such treatment capabilities.[4,9] The potential of ultrasound guided procedures has previously been described in the literature.[5,7,8] Among the aforementioned surgical pathologies most likely to occur in spaceflight, several either directly or indirectly possess possible sequelae amenable to palliative or curative treatment with ultrasound-guided catheter placement. These include appendicitis or diverticulitis complicated by abscess, cholecystitis, hemo- or pneumothorax, and ureterolithiasis resulting in obstruction or pyonephrosis. However, no studies to date have demonstrated that personnel without training at a specialist level would be able to successfully perform ultrasound-guided drain placement with remote guidance. We present this paper as proof-of-concept work to address this question.

METHODS

To simulate a patient with a drainable intraabdominal fluid collection, an anthropomorphic phantom was constructed by pouring human tissue density (0.91 $g \cdot ml^{-1}$) melted ballistics gel (ClearBallistics; Lexington, SC) into a plastic mold of a human pelvis (**Fig. 1**). A cylindrical chamber in the gel pelvis was created while cooling the gel to form a void to hold a replaceable drainable fluid collection. This chamber measured 7 cm in average diameter and 5 cm in height. Once cooled to a solid, the gel was removed from the mold. A latex disposable glove was filled with water, tied at the end, and placed in the chamber in the pelvic gel phantom to simulate a drainable fluid collection. The deformable glove filled with water conformed to the cylindrical shape of the chamber. The phantom was covered with a black latex membrane to obscure the fluid collection from the operator. There were 29 participants who were selected with the exclusion criterion of having had no dedicated training placing percutaneous drains with ultrasound guidance. These procedurally naïve subjects included 4th year medical students, physician assistant students, 1st year radiology residents prior to an interventional radiology (IR) rotation, and radiology technologists (**Table I**). This study was exempted from human subject Institutional Review Board approval as the data was collected noninvasively during an educational exercise that the subjects would be reasonably expected to undertake in the future. Of the 29 subjects, 19 performed the procedure with the guiding radiology personnel within the same building but in a different room, while 12 subjects performed the procedure with the remote guidance personnel approximately 1200 km away. An additional four control participants were then selected with the inclusion criteria of being a trained physician

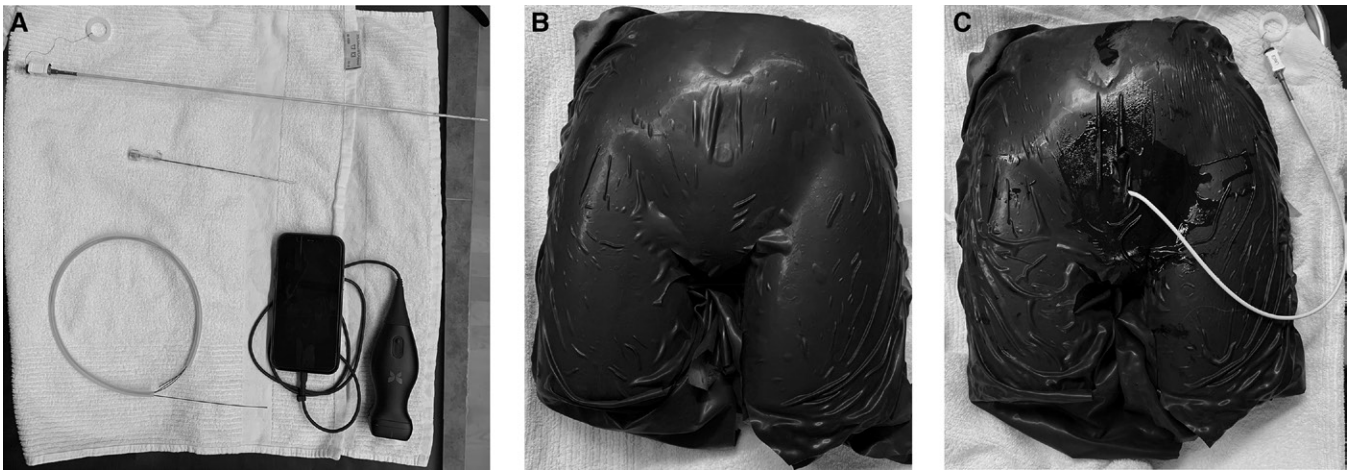

Fig. 1. Images showing the: A) initial procedure tray setup and the anthropomorphic torso phantom B) before and C) after successful insertion of percutaneous drainage catheter.

Table I. Level of Training for the 33 Study Participants.

LEVEL OF TRAINING:	NUMBER OF SUBJECTS:
Medical Student	10
Physician Assistant Student	1
Radiology Resident, no IR experience	13
Radiologic Technologist	3
Radiologic Technologist Student	2
IR-trained Physician Associate (control)	1
Attending Radiologist (control)	3

associate or attending radiologist who regularly performs ultrasound-guided procedures. These four subjects performed the simulation without assistance or remote video guidance.

The procedurally-naïve participants were first shown a 5-min tutorial video demonstrating the use of the ultrasound probe to visualize the fluid collection within the phantom and how to subsequently place a drainage catheter in stepwise fashion within the fluid collection using a 17G introducer trocar needle, a 0.035" or 0.038" guidewire, and a #10 French pigtail percutaneous drainage catheter. After watching the video, participants were placed in an exam room alone which contained a portable ultrasound probe and monitor, the pelvic phantom with preloaded drainable fluid collection, a procedure tray containing the same instruments used in the tutorial video, and a laptop/webcam connected to a two-way video call with a radiologist in a separate location. The radiologist guiding the procedure possessed fellowship-level procedural training experience. The ultrasound equipment used included a Butterfly iQ at site one (Butterfly Network, Guilford, CT) and an ACUSON S2000™ Ultrasound System, HELX™ Evolution, at site two (Siemens AG, Munich, Germany). Participants then attempted to place the drainage catheter within the fluid collection using remote assistance in a stepwise fashion as follows:

1. The participant scanned the phantom with the ultrasound unit.
2. Upon confirmation of successful target fluid collection identification by the radiologist, the participant was instructed to pick up the introducer needle and insert it a short distance into the phantom toward the target in the plane of the ultrasound probe.
3. The needle was advanced slowly in a stepwise function by the participant with the radiologist approving the trajectory at approximate 1 cm intervals (**Fig. 2**).
4. Once the radiologist deemed the needle to be at the margin of the fluid collection, the participant was instructed to advance the needle into the collection.

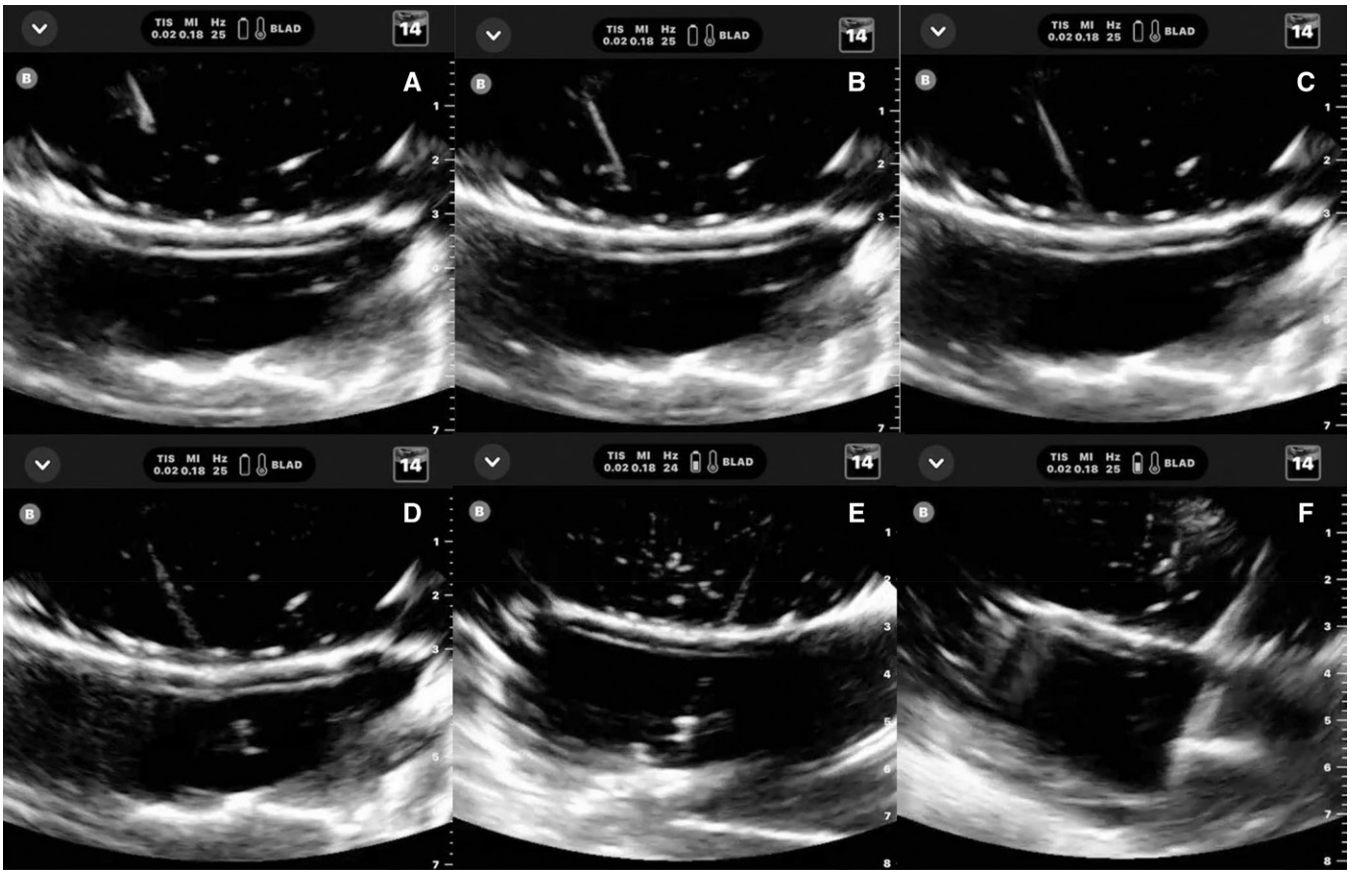

Fig. 2. Ultrasound images showing: A–D) advancement in a stepwise fashion of the introducer needle with the needle traversing A–B) simulated soft tissue, C) at the soft tissue/abscess interface, and D) with tip within the simulated abscess. In a different attempt, the 0.035" guidewire is visualized E) within the abscess through the introducer needle with F) the final position of the drain coiled within the abscess.

5. Once the radiologist confirmed the needle tip was at least 1 cm into the collection, the participant was instructed to remove the inner stylet of the introducer needle while keeping the needle in place.
6. The participant was instructed to confirm needle tip location within the fluid collection by applying pressure to the collection, resulting in expression of fluid through the needle.
7. The participant was instructed to then advance a 0.035" or 0.038" Lunderquist or Amplatz wire through the needle into the fluid collection.
8. Once initial resistance was felt by the participant, the participant was instructed to continue advancement of the wire to form a coil within the collection.
9. The participant was instructed to remove the access needle while keeping the wire in place using a "pinch pull" technique (pushing and pinching the wire in place while pulling the needle in retrograde fashion from the wire).
10. Once the needle was removed from the wire, the participant was instructed to place the prepared drain onto the wire and advance the drain to the surface of the phantom.
11. The participant was then instructed to advance the drain over the wire into the fluid collection using a "pinch and push" technique (pinching the wire to keep it in place while slowly advancing the drain forward through the simulated tissues).
12. When resistance was felt by the participant, the participant was instructed to use ultrasound to visualize the drain tip within the collection. The positioning was confirmed by examination of the images by the radiologist.
13. The participant was then instructed to remove the inner stylet/stiffener and wire in retrograde fashion while advancing the drain to form the coil within the fluid collection.

Technical success was defined as placing the catheter coiled tip within the fluid collection. Confirmation of technical success was assessed by applying pressure to the phantom resulting in expression of fluid and/or aspiration of fluid with a syringe via the drain. The number of needle redirections and the time to perform the procedure were also recorded for each participant. The mean and standard deviation for each variable were calculated for both groups and compared using an unequal variance (Welch's) *t*-test.

RESULTS

There were 31 interventional radiology-naïve participants recruited. One was urgently summoned to hospital duties during the procedure and the attempt was aborted. In another attempt, the phantom experienced a mechanical failure. Of the remaining participants, all 29 demonstrated technical success (**Table II**). Of these, 26 successfully placed the catheter without the need to redirect the trocar needle, while three required a single needle redirection. No participants required more than one redirection. The time to perform the procedure ranged from 4 to 11 min, with a mean time of 5.8 min. Four attending radiologists and physician associates (PA) at a major academic hospital with experience performing ultrasound guided procedures also completed the simulation. All four subjects demonstrated technical success with one participant requiring one redirection. All four control subjects required 2 min for completion.

Table II. Rates of Success, Time to Completion, and Number of Redirections for Test and Control Groups.

GROUP	MEAN	SD	RANGE	UNEQUAL VARIANCES *t*-TEST *P*-VALUE
Test Group [Technical Success: 100% (29/29)]				
Minutes to Completion	5.8	±1.4	4 to 11	
Redirections	0.1	±0.4	0 to 1	
Control Group [Technical Success: 100% (4/4)]				
Minutes to Completion	2	±0	2 to 2	<0.001
Redirections	0.25	±0.5	0 to 1	0.69

DISCUSSION

Treatment goals for surgical intervention in the space environment involve maximizing the ability to treat a variety of pathologies while minimizing equipment mass and volume, procedural complexity, and complication rate.[2] Ultrasound-guided percutaneous drain placement can be used to symptomatically palliate or curatively treat a multitude of potential surgical emergencies which may be encountered during spaceflight, particularly exploration class missions for which medical evacuation is not possible.[5,7,9] Conditions specifically included on the NASA Exploration Medical Capabilities list whose potential sequelae may be amenable to this intervention include abdominal injury, appendicitis, nephrolithiasis, urinary retention with stricture, acute cholecystitis, acute pancreatitis, and acute diverticulitis.[15] This list was formulated based on conditions with a potential to occur in spaceflight based on analog populations and historical spaceflight incidence data. Ultrasound-guided percutaneous drain placement is also relatively low risk, quickly learned, and can be performed with minimal equipment.[11] This limited equipment requirement minimizes the mass and volume penalty with far less than a kilogram required for the entire system if excluding the mass of the ultrasound probe.[9] There is no need for general anesthesia or moderate sedation, and there is potential for rapid recovery of the crewmember to near full function. Furthermore, it can be performed in a stepwise process, allowing for guidance by a remote terrestrial guide and/or audiovisual teaching tool.

As current missions do not extend beyond low Earth orbit and medical evacuation to high level of terrestrial care is available within 24 h, the need for such guided interventions has not yet been urgent. However, planned lunar and Martian missions

lasting months to years, including future Artemis missions, extend beyond the safety net of emergent evacuation and treatment. Surgical emergencies would require immediate largely autonomous treatment capabilities. There are at present no fellowship-trained interventional radiologists or other similar imaging-guided proceduralists in the NASA Astronaut Corps. However, there are personnel with backgrounds in emergency medicine, general surgery, and internal medicine, among others, who may be able to quickly master basic imaging-guided procedural skills. Given the high rate of technical success, the technique presented in this paper may be effective to allow for just-in-time training of these highly educated personnel when and where live guidance is available.

Multiple study limitations were present, some of which were unavoidable, including but not limited to the small size of the control group, lack of microgravity, no significant differences in tissue densities between gel and fluid on ultrasound, and only minimal delay in video communication. Additionally, the simulated "patient" in this case does not fully mirror the challenges of drain placement on a live subject, particularly one who is acutely ill and potentially physically incapacitated. Of particular concern are difficulties of patient immobilization, administration of local anesthetic, and control of the small volume of bodily fluids (blood, pus, urine, etc.) likely to be generated during catheter insertion. None of these challenges could be evaluated well with our experimental setup but will complicate the procedure in spaceflight.

However, this proof-of-concept work does demonstrate that this sample of educated but minimally to nonprocedurally trained individuals could consistently successfully complete the steps required for percutaneous drainage when provided with a brief instructional video and live guidance. Despite the small sample size, the procedurally naïve participants required a statistically significantly longer period of time to complete the procedure compared to the experienced physicians and physician assistants, but there was no statistically significant difference in needle redirections. This work also supports the proposition that just-in-time training with two-way live audiovisual support from a remote expert may represent a feasible pathway for avoiding dedicated extensive preflight training in these minimally-invasive surgical interventions. This capability to successfully teach then guide such procedures remotely, however, could also be applied to terrestrial environments, such as polar research stations, submarines, and resource-limited regions of the developing world. While the minimal communications delay present in our setup might simulate well the near future potential low Earth orbit, cis-lunar, and some near-Earth asteroid intercept missions, exploration class Mars missions with longer delays will require further study, as two-way communication times will extend up to 40 min.[10] In addition to testing longer communication delays utilizing this method of instruction and stepwise guidance, further work should explore its implementation in more closely related analogs to microgravity, such as parabolic or suborbital flight.

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Authors and Affiliations: David J. Lerner, M.D., University of Washington, Seattle, WA; Michael S. Pohlen, M.D., and Sherveen N. Parivash, M.D., M.Sc., Stanford University, Stanford, CA; and Robert C. Apland, D.O., Radia Inc., Lynnwood, WA.

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