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Remote just-in-time telementored trauma ultrasound: a double-factorial randomized controlled trial examining fluid detection and remote knobology control through an ultrasound graphic user interface display

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Abstract

BACKGROUND: Remote-telementored ultrasound involves novice examiners being remotely guided by experts using informatic-technologies. However, requiring a novice to perform ultrasound is a cognitively demanding task exacerbated by unfamiliarity with ultrasound-machine controls. We incorporated a randomized evaluation of using remote control of the ultrasound functionality (knobology) within a study in which the images generated by distant naive examiners were viewed on an ultrasound graphic user interface (GUI) display viewed on laptop computers by mentors in different cities.

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METHODS: Fire-fighters in Edmonton (101) were remotely mentored from Calgary ($n = 65$), Nanaimo ($n = 19$), and Memphis ($n = 17$) to examine an ultrasound phantom randomized to contain free fluid or not. Remote mentors (2 surgeons, 1 internist, and 1 ED physician) were randomly assigned to use GUI knobology control during mentoring (GUIK+/GUIK−).

RESULTS: Remote-telementored ultrasound was feasible in all cases. Overall accuracy for fluid detection was 97% (confidence interval = 91 to 99%) with 3 false negatives (FNs). Positive/negative likelihood ratios were infinity/0.0625. One FN occurred with the GUIK+ and 2 without (GUIK−). There were no statistical test performance differences in either group (GUIK+ and GUIK−).

CONCLUSIONS: Ultrasound-naive 1st responders can be remotely mentored with high accuracy, although providing basic remote control of the knobology did not affect outcomes.

Traumatic injury continues to be the leading cause of potentially preventable years of life lost in our society.[1–3] The early management of catastrophic trauma is critical to salvaging the most critically injured and avoiding unnecessary morbidity.[4] Thus, ultrasound, which offers almost unlimited scope of enhancing bedside care in the critically ill/injured is an indispensable tool that, ideally, would always be immediately available.[5,6] As ultrasound technology becomes smaller and less expensive there is often a disconnect between the availability of trained ultrasonographers and ultrasound machines. This is the situation in space medicine. An ultrasound machine is the only medical-imaging capability onboard the International Space Station,[7–9] yet nonphysicians may be required to make critical diagnoses and provide invasive therapies to fellow crew members.[10,11] This led investigators with the National Aerospace and Aeronautics Administration to pioneer remote guidance techniques, wherein a novice care-provider onboard the International Space Station is mentored to obtain meaningful ultrasound images interpreted by terrestrial experts to guide diagnosis and therapy.[10–13] Although this paradigm to providing medical imaging in remote and austere environments has now become the standard of care in space medicine, the potential of this disruptive technology is only being cautiously explored terrestrially.[14]

There has been little study of the human-machine interactions required to facilitate remote-telementored ultrasound (RTMUS). Most smart computing/communicating devices now use graphic user interfaces (GUIs), which reduce user learning curves to control powerful electronics. Newer ultrasound machines are essentially specialized computers in which the physical knobs and switches have been digitally replaced. “Knobology” in reference to the performance of ultrasound is defined as “operating the ultrasound-machine controls”.[15] Previous study in our institution has demonstrated that knobology requirements maybe quite detrimental to the learning task and disproportionately burden the cognitive load of novices.[15] GUI control and display capabilities are an innovation that frees the ultrasound image generating hardware from its control software. This technology thus offers the option to shift the responsibility for knobology control from the novice performing ultrasound to the remote mentor directing the examination. We thus sought to prospectively study whether; (A) RTMUS diagnoses of a simulated massive hemoperitoneum could be conducted by novices while experts viewed the examination on a remote ultrasound GUI interface, and (B) whether remotely controlling the knobology on behalf of the inexperienced examiners improved accuracy and efficiency.

Methods

A prospective double-factorial–randomized control design was used. City of Edmonton fire-fighters performed the examinations within fire halls throughout the city. All participants volunteered and were free to withdraw at any time. Remote mentors guiding these examinations were a trauma surgeon/intensivist and an internist in Calgary, Alberta; an emergentologist in Nanaimo, British Columbia, and a trauma surgeon/intensivist in Memphis, Tennessee (Table 1). Ethics approval was provided by the University of Calgary (E-20949). The study used an ultrasound phantom examined by completely inexperienced and remotely mentored fire-fighters. The ultrasound Phantom (FAST Exam Real-Time Ultrasound Training Model, CAE Healthcare, Sarasota, FL) provided a capacity to introduce/withdraw fluid.

The primary outcome was diagnostic accuracy for free-fluid detection determined by the remote mentor related to: (A) true presence/absence of significant fluid within the right upper quadrant of the phantom and (B) ability to use remote control of the ultrasound knobology by the mentor during the examination. Secondary outcomes addressed qualitative issues related to user perceptions and satisfaction with the RTMUS concept and the specific use of the GUI.

The SonicTelemed system (SonixTelemed, Ultrasonix Corporation, Richmond, British Columbia, Canada) is a software package enabling remote control of an Ultrasonix scanner over an IP network and real-time streaming of ultrasound images from the scanner to connected clients. It includes a GUI providing real-time video display of the remote examination and visual controls for the user to interact with the ultrasound scanner and change its configuration remotely, as if they were using the buttons located on the ultrasound machine itself (Fig. 1). The specific technological parameters adjustable by the remote mentor are described in Table 2.

Table 1 Remote mentors' equipment and characteristics

Mentor (MD)* (in practice)†	Mentoring location	Mentoring experience prior hours‡	Smart device	Exams mentored	Errors
Trauma surgeon (27 y) (17 y)	Calgary Alberta	yes (100 h)	HP ProBook 4520s Laptop	33	1 FN
Internist (16 y) (10 y)	Calgary Alberta	No	DELL Optiplex 960	32	0
Trauma surgeon (8 y) (PGY8)	Memphis Tennessee	yes (5 h)	Acer Aspire E15	17	2 FN
Emergency physician (17 y) (14 y)	Nanaimo British Columbia	No	Toshiba Satellite Windows 7 4 GB RAM 64 bit operating	19	0

FN = false negative; MD = Medical Doctor; PGY = Post Graduate Year.
*Years in practice since medical school graduation.
†Years in practice after completing specialty training.
‡Prior ultrasound telementoring experience (yes/no) and estimated prior hours of activity.

Each examination was randomly allocated as to whether the phantom contained 750 ml of fluid or not (double blinded) and secondly to whether remote control of the ultrasound "knobology" (unblinded) was used or not. The fire-fighters were shown the phantom and the ultrasound machine before the remote examination but were not permitted to practice. Each examination was limited to 5 minutes total duration to simulate "just-in-time" emergency conditions. Ultrasound images were viewed remotely in real-time by the mentors on their own commercial-off-the-shelf mobile computing devices (Table 1). Commercial-off-the-shelf laptop computers connected to the internet at both the fire hall and the remote mentors office/home provided the architecture for audiovisual communication. Each fire-fighter wore a head-mounted 1.3 Megapixel video camera (Fig. 2; Microsoft, Redmond, WA) which enabled the remote mentor to view the fire-fighters hands, ultrasound probe, and ultrasound phantom when transmitted using the "share my screen" function of Skype. On the mentor's computer, this view of the fire-fighters handling of the ultrasound probe was overlaid onto the larger SonixTelemed system software display of the ultrasound image and the "knobology" controls (Fig. 1).

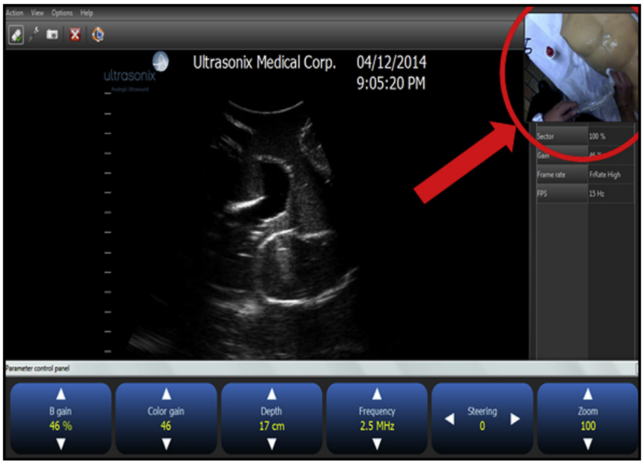

Figure 1 Visual ultrasound information presented to the remote mentor guiding the fire-fighters focused ultrasound examination. Large image depicts the graphic user interface as displayed on the remote mentors portable computing device. The red arrow and circle emphasize the display of the fire-fighters hands and ultrasound probe as imbedded onto the larger graphic user interface display. The imbedded window could be enlarged as desired by the mentor.

Before conducting any actual study examinations, the remote mentors received an on-line familiarization tutorial hosted by the PI in Calgary and the Edmonton support team. Remote mentors were briefed on the ultrasound and GUI function, and coached through 2 nonstudy scans of the phantom with and without fluid. After initial introductions, the mentor was allowed to conduct the RMTUS examination however they saw fit. All mentors began with a brief explanation to the fire-fighter as to probe orientation and basic movements minimizing the use of medical verbiage. They thereafter guided the fire-fighters using plain English. The goal was to manipulate the probe under their guidance to attempt to best visualize the anatomy of the phantom's right upper quadrant to determine the presence or not of significant fluid. Although remote mentors captured representative screen-shots for

Table 2 Knobology parameters that were remotely controllable using the GUI software

Ultrasound parameter	Functionality
B gain	Fully controllable from the remote GUI
Color gain	Partially controllable from the remote GUI
M-Mode	Partially controllable from the remote GUI
Depth	Fully controllable from the remote GUI
Frequency	Fully controllable from the remote GUI
Zoom	Fully controllable from the remote GUI
Freeze	Fully controllable from the remote GUI

GUI = graphic user interphase.

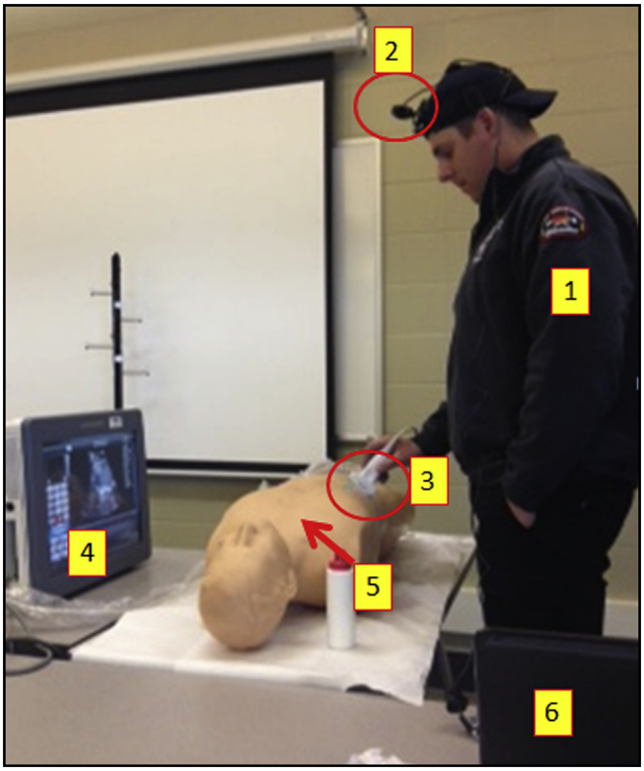

Figure 2 Fire-fighter performing a remote mentored tele-ultrasound examination. Fire-fighter (1), wearing portable head-camera (2), holding the ultrasound probe (3), of the ultrasound machine (4), examining the ultrasound phantom (5), being guided by the remote mentor over the laptop computer (6).

documentation they were required to make a final determination of the presence of significant free fluid–based solely on the 5-minute examination. At completion both the fire-fighters and remote mentors completed post-test experience surveys (Supplementary Figs. 1 and 2).

Statistical analysis

T-tests were used to assess for differences between age or years of experience as a paramedic between the GUIK+ and GUIK− groups. Mann-Whitney U tests were used to compare number of years as a fire-fighter and all postexamination impression questions. We considered 2-sided *P* values less than .05 significant.

Results

Demographics

All 101 fire-fighters approached agreed to participate. The phantom was randomized to fluid-filled in 47 examinations and drained for 54. Fifty-three of these examinations were randomized to GUIK+ and 48 to GUIK− (Table 3). All examinations were completed per protocol. The mean age for all recruited fire-fighters was 37.6 ± 8.6 years. No fire-fighter in either group had any prior ultrasound experience. There was no difference in mean age between the 53 fire-fighters conducting examinations randomized to GUIK+ (37.1 ± 8.7 years) and the 48 allocated to GUIK− (37.3 ± 8.6 years; *P* = .460). The mean years of experience of the entire group as fire-fighters were 9.9 ± 6.8 years and as paramedics were 9.1 ± 5.1 years. There was no significant difference between years of experience at either designation between the 2 groups (*P* = .902, and *P* = .119, respectively).

Overall remote-telementored ultrasound accuracy for free-fluid detection

For all the examinations conducted, the remote mentor group was able to achieve an accuracy of 97% (95% confidence interval [CI], 91.6 to 99.4), sensitivity of 94% (95% CI 83 to 99), specificity of 100% (95% CI 93 to 100), positive predictive value of 100% (95% CI 92 to 100), negative predictive value of 95% (95% CI 85 to 99), for the assessing the correct status of free fluid within the phantom. The likelihood ratio (LR) of a positive test was infinity with the LR of a negative test being .06 (95% CI .01 to .3; Table 4).

RTMUS accuracy for free-fluid detection related to use or not of the GUI-knobology function

Fifty-three examinations were randomized to GUIK+. With this adjunct, the sensitivity was 96% (95% CI = 80.3 to 99.4), specificity 100% (95% CI = 87.1 to 100), accuracy 98.1% (95% CI = 91% to 99%), positive predictive value 100% (95% CI = 86.2 to 100), and negative predictive value 96.4% (95% CI = 81.6 to 99.4; Table 4). The LR of a positive test was infinity and the LR of a negative test was .04 (95% CI = .01 to .26). Forty-eight examinations were randomized to GUIK−. Without knobology remote control, the sensitivity was 91.0% (95% CI = 70.8 to 98.6), specificity 100% (95% CI = 86.7 to 100), accuracy 95.8% (95% CI = 86 to 100), positive predictive value 100% (95% CI = 83.0 to 100), and negative predictive value 92.9% (95% CI = 76.5 to 98.9; Table 4). The LR of a positive test was infinity and the LR of a negative test was .09 (95% CI = .02 to .34).

Table 3 Double factorial randomization details

Examination randomized to	
Fluid present and remote control of knobology	26
No fluid present and remote control of knobology	27
Fluid present and no remote control of the knobology	22
No fluid present and no remote control of the knobology	26

Table 4 Test performance characteristics of remote-telementored ultrasound for free-fluid detection

Study group	All examinations combined	GUIK+	GUIK−
Number of examinations	101	53	48
Overall Accuracy (95% CI)	97.0% (91.6%–99.4%)	98.1% (91.0–99.0)	95.8% (85.7%–99.5%)
Sensitivity (95% CI)	93.8% (82.8%–98.7%)	96.0% (80.3%–99.4%)	91.0% (70.8%–98.6%)
Specificity (95% CI)	100.0% (93.3%–100%)	100.0% (87.1%–100%)	100.0% (86.7%–100.0%)
PPV (95% CI)	100.0% (92.1%–100%)	100.0% (86.2–100)	100.0% (83.0%–100.0%)
NPV (95% CI)	94.6% (85.1%–98.9%)	96.4% (81.6%–99.4%)	92.9% (76.5%–98.9%)
Likelihood ratio Positive test (95% CI)	infinity	infinity	infinity
Likelihood ratio negative test (95% CI)	.06 (.01–.26)	.04 (.01–.26)	.09 (.02–.34)

95% CI = 95% confidence interval; GUIK = graphic user interface knobology; NPV = negative predictive value; PPV = positive predictive value.

Fire-fighters post-test evaluations

Fire-fighters agreed the phantom was anatomically realistic (median Likert response 4/5; interquartile range [IQR] = 1; Table 5). They also agreed performing an RTMUS point-of-care examination was a realistic task for them (median Likert response 4/5; IQR = 1) and expressed confidence in their ability to do so (median Likert response 4/5; IQR = 1). They also agreed their experience with the phantom increased their confidence in performing an RTMUS (median Likert response 4/5; IQR = 1). They however, disagreed with the statement "that in their hands performing a telementored ultrasound was likely more dangerous for the patient than potentially beneficial" (median Likert response 2/5; IQR = 1). They also disagreed that there was an audio delay and that any audio delay impacted task completion (median Likert response 2/5; IQR = 1 for both). There were no statistical differences between groups in any of these responses. On average, those using the GUI strongly agreed (median Likert response 5/5; IQR = 1) they could hear the mentor well enough to perform the RTMUS, compared with those without GUI who only agreed (median Likert response 4/5; IQR = 1) although this difference was not statistically significant ($P = .857$).

Among the 53 fire-fighters randomized to use of GUI, there was median Likert response of 4/5 (IQR = 1) for the following 3 questions: (1) "If you were asked to perform a

Table 5 Summarized post-test participant opinions fire-fighters

Question (GUIK+) (GUIK−)	Number	Median Likert Score (1–5)*	Median Likert Score (1–5)*	IQR
1. "Phantom" was anatomically realistic	53	4	4	1
	48	4	4	1
2. Performing a telementored ultrasound was a realistic task for me to perform	53	4	4	1
	48	4	4	1
3. Confidence in abilities to perform a telementored ultrasound	53	4	4	1
	48	4	4	1
4. Experience with "Phantom" increased confidence to perform telementored ultrasound	53	4	4	1
	48	4	4	1
5. Performing a teleultrasound likely more dangerous than potentially beneficial	53	2	2	1
	48	2	2	1
6. There an audio delay with mentoring	53	2	2	1
	48	2	2	1
7. An audio delay impacted the ability to perform/complete	53	2	2	1
	48	2	2	1
8. Head-mounted camera impacted task completion	53	2	2	1
	48	2	2	1
9. Audio was clear enough to hear mentor	53	5	5	1
	48	4	4	1
10. If repeating would you would want the mentor to use the GUIKC†	53	4	4	1
11. Being telementored with GUIKC increased confidence†	53	4	4	1
12. Would be mentored with the GUIKC decrease your stress†	53	4	4	1

GUIK+ = graphic user interface knobology control used; GUIK− = graphic user interface knobology control not used.
*Likert Score (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).
†Questions 10–12 only answered by those randomized to use the GUIKC; IQR = interquartile range.

telementored ultrasound again you would want the mentor to use the GUI?", (2) "If you were asked to perform a telementored ultrasound again, being telementored with the GUI would increase your confidence to complete the task successfully?", and (3) "If you were asked to perform a telementored ultrasound again, being telementored with the GUI would decrease your stress while performing the task?"

Remote mentor post-test evaluations

The remote mentors ($n = 4$) as a collective agreed (median Likert response 4/5; IQR = 1) performing a telementored ultrasound was a realistic task for fire-fighters to perform and agreed (median Likert response 4/5; IQR = 1) they felt confident in the fire-fighters abilities to perform an RTMUS (Table 6). They strongly disagreed (median Likert response 1/5; IQR = 1) fire-fighter performing an RTMUS would be more dangerous for the patient than beneficial, and there was an audio delay in conducting RTMUS with the current technology (median Likert response 1/5; IQR = 0). They also uniformly strongly disagreed (median Likert response 1/5; IQR = 0) that any audio delay impacted their ability to perform the task, and uniformly strongly agreed (median Likert response 5/5; IQR = 0) that they could hear the fire-fighter clearly enough to mentor the RMTUS examination. There were no significant differences when the GUI knobology function was used vs not, for any metric.

Table 6 Summarized post-test participant opinions remote mentoring physicians

Question (GUIK+) (GUIK−)	Number	Median Likert Score (1–5)*	Median Likert Score (1–5)*	IQR
1. Performing a telementored ultrasound was a realistic task for me to perform	53 48	4 4	4 5	1 1
2. Confidence in abilities of fire-fighter to perform a telementored ultrasound	53 48	4 4	4 4	1 1
3. Performing a teleultrasound likely more dangerous than potentially beneficial	53 48	2 1	2 1	1 1
4. There was an audio delay with mentoring	53 48	2 1	1 1	1 1
5. An audio delay impacted the ability to perform/ complete	53 48	1 1	1 1	0 0
6. Head-mounted camera impacted task completion	53 48	3 3	3 1	2 2
7. Could hear the FF clearly enough to mentor	53 48	5 5	5 5	0 0

GUIK+ = graphic user interface knobology control used; GUIK− = graphic user interface knobology control not used.

*Likert Score (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree); IQR = interquartile range.

Comments

This study demonstrated that ultrasound-naive 1st responders, without prior instruction, can be remotely mentored from very distant locations to obtain potentially life-saving pathophysiologic information that would otherwise be inapparent without ultrasound. However, in this model of intraabdominal hemorrhage, providing the mentor with remote knobology control did not significantly change performance outcomes.

The extension of point-of-care ultrasound beyond in-hospital care is typically limited by the need for a trained operator. Remote just-in-time telementoring is a potential solution to overcoming this problem. Other suggested approaches are formally training prehospital providers to learn ultrasound techniques, 3-dimensional acquisition by less trained users with remote interpretation of volume gathered data,[16,17] and even robotic ultrasound examinations.[16–19] Although education is always to be encouraged, we believe that RMTUS is the most logistically simple and versatile option. This concept enables a remote expert to provide interpretation, whereas the local responder needs only to generate adequate ultrasound images.

We originally explored remote mentoring to emergency physicians in a rural referral center in Banff, Alberta in 2007. This involved trauma surgeons at the tertiary care center viewing the resuscitative bay in Banff with both a macro-field camera and real-time display of the rural ultrasound machine.[20,21] using this somewhat complex system, RTMUS was found to be not only feasible and accurate but it also improved patient triage, educated novices, and increased collegiality.[20,21] Boniface et al[22] subsequently guided paramedics remotely via 2-way radio communication through solely viewing the ultrasound images of model patients without pathology and without viewing the examiners hand or probe movements. They noted that 51 paramedics were able to generate 100% of the required FAST views, although 20 minute didactic educational sessions before scanning were required.[22] Levine[23] recently noted tele-intensivists could guide minimally trained nonphysicians to obtain high-quality, clinically useful ultrasound images. The evidence to date, however, is limited as the subjects studied were anatomically normal patients/models without pathology limiting the true clinical implications of these and similar studies.[22–25] We believe the present study is unique in using an objective and clinically relevant outcome evaluation of ultrasound accuracy and a randomized format to generate grossly normal or abnormal findings.

To our knowledge, the Canadian Space Agency sponsored tele-ultrasound link between Banff and Calgary was also the 1st evaluation of acute real-time remote trauma resuscitation guidance with ultrasound. The system however was unsustainable for 24/7 immediate response, however, as it used a fixed internet-cable link. This required additional time for the responding trauma surgeon mentors to physically travel to the tele-ultrasound console within the hospital. Subsequent efforts focused on attempting to make RTMUS simpler and in particular, reducing the infrastructure required. Investigators from Detroit championed the use of a stand-alone video compression device to stream through a secure satellite modem to allow 1-way ultrasound and video transmissions and 2-way audio from challenging environments such as Mount Everest and the Canadian Arctic.[26,27]

Continuing efforts have attempted to further simplify RTMUS. Freely available password-protected Voice over Internet Protocol software (Skype) was used to transmit combined outputs from head-mounted video and hand-held ultrasound devices. Such software permits a potential remote mentor to view ultrasound images produced by the novice and simultaneous real-time views of the novices handling of the ultrasound probe on any smart device.[28–30] Pilot investigations demonstrated the ease of using such systems from essentially any internet connection received through fixed lines, wireless networks, or tethered to cellular phone networks. RTMUS was thus conducted from rural mountainsides, from within a small airplane, and even from the United Nations building using smartphones.[28,30–33] The development of a dedicated ultrasound GUI that can be customized to a remote mentor's preferences, and potentially installed on any computing device, is another development that may advance the wide dissemination and utilization of the RTMUS technique.

By design, the study required the remote generation of ultrasound images of adequate quality to allow the accurate interpretation of the presence or not of significant intraperitoneal fluid. This objective outcome was easily and accurately obtained in 97% of the examinations with absolute novices holding the probe. This was possible without any prior didactic or hands-on training before testing as has been used by other authors.[10,22–34] Although pretraining would be desirable, such a requirement would greatly complicate the logistics when using responders who are infrequently involved in assessing major trauma. Therefore, the authors propose that with RTMUS almost any motivated 1st-responder could be remotely guided to detect serious intra-abdominal hemorrhage in the prehospital setting if the equipment and logistical support were available.

The fact that the remotely controllable knobology feature of the GUI did not measurably change the study outcomes may be 3-fold. Firstly, the highly motivated fire-fighters were able to excel with direction in generating meaningful and interpretable ultrasound images. This soundness of the basic principles behind RTMUS may be such that the task left little to improve on with remote knobology control. Secondly, the required task might have been too simple. However, detecting massive free fluid is still a critically important ultrasound task and typically one of the 1st ultrasound applications learned. Thirdly, the remote control functions were basic and limited in their robustness in terms of informatic content and special functions. In the future if more complex tasks are to be mentored, further development of remote knobology might be expanded. These might include more complete coverage of ultrasound-machine control functions, and potentially include educational tools such as telestration.[35] Although no significant differences resulted from the use of remote ultrasound control, the end users (fire-fighters) were universally reassured knowing the mentor could assist with controlling their ultrasound machine knobology if required. All questioned wished to have this function available for any potential future use.

Limitations of this study were the use of a phantom rather than truly injured patients. Only still images were recorded from each examination. Future examinations might benefit from over reading by blinded experts although the high accuracy made this irrelevant in this particular study. In retrospect, the major limitation may have been the relative simplicity of the task. Although the fire-fighters were confidant (but not over confidant) in their abilities, it was the opinion of the mentors that much more difficult tasks would have been feasible. With such tasks, potentially there might have been a greater need and thus utility for remote control of the knobology. By design the examination of the phantom did not examine all quadrants of a typical FAST examination.[36] The intent of the study was to assess the potential for a quick screening assessment that would minimally impact prehospital time. A single examination of the right upper quadrant is a powerful determinant of whether massive hemoperitoneum is present.[37] Furthermore, although this particular examination was selected for study standardization purposes, in the future and any ultrasound examination deemed appropriate by the responsible physician could be attempted, potentially even during transportation if the transport vehicle had internet connectivity.

Thus, future studies should continue examining the utility of using RTMUS in increasingly complex transverse ultrasound examinations,[38] such as those augmenting pneumothorax detection[39,40] or cardiac function to the basic FAST examination.[41] Our previous experiences suggest that remotely detecting pneumothoraces would be as easy or easier than detecting free fluid,[20] and draining a tension pneumothorax is a recognized prehospital intervention. Whether embedding ultrasound as one modality within a more complete prehospital assessment incorporating other remotely transmitted medical information should also be evaluated.[42] The most important level of evaluation, however, will be to demonstrate such technologies benefit decision-making and patient outcomes. As a great percentage of the developing world lacks adequate medical services; including medical imaging, the ability to remotely diagnose, teach, and mentor seems to offer a remote outreach with limitless potential.

Conclusions

Untrained ultrasound-naive 1st responders can be remotely mentored using remotely telementored ultrasound displayed and controlled on a GUI interface to detect critical pathology, in the model examined however, providing the mentor with basic remote control knobology did not affect outcomes. As the potential task complexity increases, remote control may become increasingly more important and further refinement of this adjunct to RTMUS should continue.

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Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.amjsurg.2016.01.018.

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POST STUDY QUESTIONNAIRE

Please circle the number below each question that best reflects your answer to the question.

1. The "Phantom" was anatomically realistic

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

2. Performing a tele-mentored ultrasound was a realistic task for me to perform.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

3. I feel confident in my current abilities to perform a tele-mentored ultrasound

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

4. My experience today with the "Phantom" has increased my confidence in being able to perform a tele-mentored ultrasound

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

5. In my hands performing a tele-mentored ultrasound is likely more dangerous for the patient than potentially beneficial

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

6. While being telementored, was there an audio delay?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

7. If there was an audio delay it impacted your ability to perform/complete the task

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

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8. While you were telementored, the head mounted camera impacted your ability to perform/complete the task

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

9. While you were telementored you could hear the mentor clearly enough to follow instructions?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Answer questions only if you were telementored with the GUI:

10. If you were asked to perform a tele-mentored ultrasound again you would want the mentor to use the GUI?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

11. If you were asked to perform a tele-mentored ultrasound again, being tele-mentored with the GUI would increase your confidence to complete the task successfully

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

12. If you were asked to perform a tele-mentored ultrasound again, being tele-mentored with the GUI would decrease your stress while performing the task?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

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Supplementary Figure 1 Post-test user experience survey for fire-fighters.

POST STUDY QUESTIONNAIRE

Mentor

Please circle the number below each question that best reflects your answer to the question.

1. Performing a tele-mentored ultrasound was a realistic task for this firefighter to perform.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

2. I feel confident in this firefighters current abilities to perform a tele-mentored ultrasound

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

3. In the hands of this firefighter, performing a tele-mentored ultrasound is likely more dangerous for the patient than potentially beneficial

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

4. While telementoring, was there an audio delay?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

5. If there was an audio delay it impacted your ability to perform/complete the task

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

6. While you were telementoring, the head mounted camera impacted your ability to perform/complete the task

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

7. While you were telementoring you could hear the firefighter clearly enough to mentor them

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

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Answer questions only if you were telementoring with the GUI:

8. If you were asked to perform a tele-mentored ultrasound again you would want use the GUI?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

9. If you were asked to perform a tele-mentored ultrasound again, tele-mentoring with the GUI would increase your confidence to complete the task successfully

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

10. If you were asked to perform a tele-mentored ultrasound again, being tele-mentoring with the GUI would decrease your stress while performing the task?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

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Supplementary Figure 2 Post-test user experience survey for remote mentors.