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ORIGINAL RESEARCH

The Feasibility of Using Ultrasound and Video Laryngoscopy in a Mobile Telemedicine Consult

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Abstract

Emergency healthcare systems in rural communities often have limited access to experienced trauma and emergency physicians. Advanced telecommunication technologies may offer an opportunity to help meet this need. We evaluated healthcare providers' satisfaction with the audio and visual components of an existing telemedicine system, and asked them whether emergency medical services (EMS) personnel could be supported via telemedicine guidance, using video laryngoscopy and ultrasonography, during vulnerable transport periods. Physicians and technologists at a central workstation were linked to a telemedicine-equipped ambulance providing real-time audio and visual communications during patient transport. A scoring system was created for system evaluation using a scale of 1–9. Seven evaluators observed ultrasonography of the carotid vessels and abdominal aorta. Nine evaluators observed an intubation with video laryngoscopy. These observers rated the quality of the images transmitted from the ambulance. Evaluators were asked if this telemedicine system would be suitable for telementoring advanced technical procedures. Mean rating for technical satisfaction with ultrasound was 5.1, the majority of evaluators estimated that they could telementor an abdominal ultrasound examination. The mean rating for technical satisfaction with laryngoscopy was 7.2 with 100% of evaluators estimating they could use the system to telementor intubation. The rating for laryngoscopy was significantly higher than for ultrasound (p = 0.01). Results of this study suggest that telemedicine may provide an advanced support mechanism for rural EMS personnel and patients. Procedures for advanced airway management and ultrasound diagnosis may someday be managed using a remote telepresence.

Key words: *ultrasound, video laryngoscopy, mobile telemedicine, emergency medical services*

Introduction

Providing emergency healthcare in rural communities poses unique challenges. In particular, rural trauma is a concern, since the availability of experienced medical providers is often limited. Although it is estimated that one third of the United States population resides in rural areas, rural residents contribute a disproportionate share (56.9%) of the deaths from motor vehicle crashes.[1] Though the reasons for this discrepancy are unclear, several possible explanations have been proposed.[2] Serious trauma is a low-volume occurrence in rural regions, so first responders and emergency room staff have less experience in managing these situations.[2–5] Rural emergency medical services (EMS) providers, often part-time volunteers, generally have less training and lower levels of certification compared to similar providers in urban areas, limiting the interventions at the scene or en route to the hospital. Additionally, transport times and the time to trauma discovery can be longer for trauma victims in a rural area.[2]

The use of mobile telemedicine systems for supporting ambulance personnel and patients has been explored by several medical research

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centers over the past 10 years. The University of Maryland program was the first to use cellular phones for transmitting single images from a moving ambulance.[6] The Center of Excellence for Remote Medically Under Served Areas has also developed a mobile medical telecommunications vehicle and telemedicine ambulance that uses radio and satellite communications technologies.[7] In San Antonio, the LifeLink project uses a citywide wi-fi system to transmit images from the ambulance to the hospital.[7] However, the most robust implementation has been the collaborative project between Texas A&M University and the U.S. Army Telemedicine and Advanced Technology Research Center, which developed the Disaster Relief and Emergency Medical Services ambulance with onboard capabilities to transmit vital signs, video images, and geographic positioning system location using satellite, radio, or cellular connections.[8]

The University of Vermont College of Medicine and Fletcher Allen Health Care in Burlington, Vermont, have made improvements in access to rural healthcare through the use of an interactive video telemedicine system that allows trauma surgeons to immediately consult at any time with rural emergency room healthcare providers.[9,10] Although telemedicine offers the opportunity for a consultation by experienced trauma specialists to rural community emergency rooms, a gap in the continuity of care occurs during transport between the rural hospital and advanced trauma-emergency center. This vulnerable transport time was addressed with the implementation of a program we called the Fletcher Allen Specialized Telemedicine for Supporting Transfer and Rescue (FAST STAR) ambulance system. The FAST STAR system was a first step toward providing advanced medical support in a moving ambulance.[10] Our project examined whether experienced physicians at the trauma center could support and guide EMS technicians in the FAST STAR ambulance during advanced procedures, such as ultrasound and endotracheal intubation, during a mobile telemedicine consult.

We hypothesized that transmitting vascular ultrasound video and video laryngoscopy from a moving ambulance via telemedicine to physicians in the trauma center would allow the physicians to obtain clinically useful information and help to better manage the patient.

Materials and Methods

This work was approved by the University of Vermont Committee on Human Research.

TELEMEDICINE EQUIPMENT

The FAST STAR system was used during the evaluation of the ultrasound images and video laryngoscope intubation sequences. The ambulance system is equipped with one-way video (from the ambulance to the physician workstation) and two-way audio. The FAST STAR system transmits over the commercial 3-G cellular network, which interconnects with the public Internet. A single cellular connection does not provide sufficient bandwidth for the video, audio, and control needs of this project. Therefore, multiple cellular channels were employed,[11] much like the Vermont teletrauma uses three ISDN lines to support rural trauma patients.[12] The audio data and control data are transmitted over one cellular channel, while the video data is multiplexed and transmitted over five other cellular channels. The system uses a motion wavelet library with spatial decompression, enabling the physician to receive higher-resolution full motion video in a designated area of interest when viewing from the ceiling-mounted cameras. The software allows one to toggle between two full-motion video inputs: the overhead cameras (not evaluated in this study) and the video from either the ultrasound or laryngoscope. A monitor is installed in the ambulance as well as at the physician workstation for viewing the patient images. The frame rate and image quality were interdependent factors, with better image quality achieved with lower frame rates and better motion (higher frame rates) with lower image quality. These factors could be adjusted by the operator at the physician workstation. Because of the highly volatile transmission environment, lost data packets were not retransmitted. This means that there is the possibility for drop out, which may interrupt the flow of audio or video images during transmission.

ULTRASOUND EQUIPMENT

A Sonosite 180 Plus portable ultrasound system (Sonosite, Inc., Bothell, WA) was equipped with an L38/10-5 MHz transducer for carotid exams and a C15/4-2 MHz transducer for the abdominal exams.

VIDEO LARYNGOSCOPY EQUIPMENT

A Karl Storz Medipac portable video laryngoscope (Karl Storz Imaging, Goleta, CA) with an Integrated DCI (Direct Couple Interface) camera was used.

PARTICIPANTS

During the ultrasound portion of our testing, an experienced clinical ultrasound technologist was the sole operator of the ultrasound probe in the moving ambulance. Carotid vessels and the abdominal aorta were imaged in real time on a single subject. The single ambulance-based technologist imaged the carotid and aorta on the single test subject while transmitting live video images and having a two-way conversation with the physician who was observing from the physician's workstation in the hospital. While we realize an ambulance crew would not have a trained ultrasound technologist, because this is a feasibility study we did not want to introduce another variable to the evaluation by using an inexperienced ultrasound operator, because ultrasonography and equipment operation is complex.

During the endotracheal intubation testing, an inexperienced individual (third-year medical student in surgery rotation) operated the video laryngoscope. Intubation was performed on a standard mannequin (Ambu Intubation Trainer, Ambu, Inc., Glen Burnie, MD) from the moving ambulance while the hospital-based physician provided real-time instruction over the FAST STAR system.

Both the ultrasound and endotracheal intubations were done in the ambulance and transmitted via the telemedicine system to the fixed location in the hospital in real-time (i.e., recorded sessions were not

Table 1. User Ratings for Ultrasound

	MEAN	SD	RANGE
Total no. respondents: 7			
Gender: n (%) male 4 (57%)			
Age	40.8	±6.6	35–51
QUIS results			
3. Overall user reactions to the system			
3.1 1 = terrible–9 = wonderful	4.9	±2.7	2–9
3.2 1 = frustrating–9 = satisfying	4.9	±2.3	2–8
3.3 1 = dull–9 = stimulating	6.2	±2.1	4–9
3.4 1 = difficult–9 = easy	6.0	±2.4	2–8
Overall mean	5.3	±2.2	2.0–8.5
4. Screen			
4.1 Characters on screen: 1 = hard to read–9 = easy to read	6.0	±2.4	2–8
4.2 Highlighting on screen: 1 = unhelpful–9 = helpful	6.4	±1.8	4–8
4.3 Screen layouts helpful: 1 = never–9 = always	6.8	±1.5	5–8
4.4 Sequence of screens: 1 = confusing–9 = clear	5.7	±2.1	4–8
Overall mean	6.7	±1.6	4.5–8.0
10. Multimedia			
10.1 Quality of still pictures/photos: 1 = bad–9 = good	4.0	±2.9	1–7
10.2 Quality of movies: 1 = bad–9 = good	2.7	±2.1	1–5
10.2.1 Focus of movie images: 1 = fuzzy–9 = clear	3.0	±1.9	1–5
10.2.2 Brightness of movie images: 1 = dim–9 = bright	4.0	±2.3	2–7
10.2.3 Window size adequate: 1 = never–9 = always	4.8	±3.9	1–9
10.3 Sound output: 1 = inaudible–9 = audible	7.2	±0.8	6–8
10.3.1 Sound output: 1 = choppy–9 = smooth	6.6	±1.7	4–8
10.3.2 Sound output: 1 = garbled–9 = clear	7.0	±2.0	4–8
10.4 Colors used are: 1 = unnatural–9 = natural	6.0	±1.2	5–7
Overall mean	5.1	±1.7	2.9–6.9
Mean of all items	5.1	±1.6	2.4–7.2

QUIs, Questionnaire for User Interaction Satisfaction.

used: each session was conducted live). Besides the video image, two-way audio was used between the ambulance crew and hospital-based physician during all medical simulations.

Evaluators of the ultrasound portion included 4 physicians (two trauma surgeons, two emergency room physicians) as well as three experienced ultrasound technologists. The evaluators of the video laryngoscope intubation included nine emergency and trauma physicians.

QUESTIONNAIRE FOR USER INTERACTION SATISFACTION (QUIS)

A modified Questionnaire for User Interaction Satisfaction (QUIS)[13,14] was filled out by seven evaluators of the ultrasound procedures and nine evaluators of the laryngoscopy. QUIS is a validated questionnaire for obtaining user feedback on the human–computer interface, covering issues such as screen characteristics, learning factors, and multimedia quality. QUIS was modified to contain only the sections relevant to each scenario. All items were answered on a 1–9 scale, with anchors at the ends such as "difficult" for 1 and "easy" for 9. For all items, a higher score indicated a more positive user experience. (A choice of "NA" was also available for each item, so not all items received ratings from all respondents.) A series of open-ended questions was also asked of the evaluators.

TRANSMISSION AND IMAGE EVALUATION

The aggregate transmission bandwidth was measured at specific locations during vehicle movement on typical ambulance run routes and compared to the expected aggregate bandwidth available through the 3-G cellular network when using five channels for video data transmission. Image resolution was measured with the ambulance at rest by transmitting live video of a standard resolution imaging chart (Edmunds Scientific) with measurements taken from a video monitor connected directly to the overhead camera, on the EMT workstation monitor and at the physician workstation.

Results

ULTRASOUND

QUIS results are reported in *Table 1*. Responses varied widely among the seven viewers. For example, for the first item in overall user reactions to the system (rated as 1 = terrible through 9 = wonderful), one viewer scored this as a 2, two put 3, and there was one each for 4, 5, 8, and 9. Because the consultations were done in real time, evaluators could examine the same anatomic area but not the exact same image. This may explain the variability in ratings.

The mean rating across all items was 5.1 $\pm$ 1.6 on the scale of 1–9. The mean ranged from 2.7 to 7.2. The range of responses was much wider than for general users of FAST STAR or those using it for intubation (see below).

In addition to QUIS, evaluators responded to this additional question as follows:

Assuming that the ambulance crew had additional training (in operation of an ultrasound machine and handling of the ultrasound probe), could you use this system to telementor a Focused Abdominal Ultrasound for Trauma?

Yes	3 (50%)
No	3 (50%)
Did not answer	1

INTUBATION

QUIS responses for the nine intubation evaluators are presented in *Table 2*. The mean rating across all items of 7.2 was significantly higher than the mean of 5.1 for ultrasound (Wilcoxon rank sum test p value = 0.01), indicating an overall more favorable rating of the system for intubation than for ultrasound.

In addition to QUIS, all nine evaluators responded to this additional question ("Assuming that the ambulance crew had additional training, could you use this system to telementor intubation?") in the affirmative (100%).

Transmission and image quality. The results indicated that each phone was transmitting between 17 and 85 kbps during the download tests, or about 50% of the published specification for 3-G cellular phones. The transmission rates were also measured during mobile testing sessions by measuring the incoming data from the ambulance received on the physician's workstation. The maximum data rate received was between 125 and 150 kbps, but the average data rate was measured at a constant 50–70 kbps. Again, the actual data rates were lower than the estimated data rates.

Image resolution testing showed that the compression scheme had a negative effect on image quality through processing and not transmission. Both the compressed image viewed on the FAST STAR ambulance workstation and the transmitted image viewed on the physician workstation received the same score with the standardized resolution test target. Though both the compressed and transmitted images were of equal value in terms of resolution, these values represented a 49.9% reduction in resolution from the uncompressed baseline image observed in a direct connection between the overhead camera and a video monitor.

Discussion

This project demonstrates that telementoring the use of peripheral equipment, such as ultrasound and video laryngoscopic intubation, is possible in a telemedicine-equipped ambulance. Our statistical analysis revealed a significantly higher mean satisfaction with the video assistance of laryngoscopic intubation than was found for the ultrasound imaging. This suggests that the prototype FAST STAR system may be better suited for video laryngoscopy than for ultrasound, which generally presents more moving images than the single viewpoint of the laryngoscope.

During the telemedicine consults that evaluated ultrasound imaging, there were lower ratings for video than for still pictures, with no respondent giving a rating higher than 5 for quality and focus of video. In an open comment section included on the QUIS, evaluators made reference to video problems and one wrote "frame rate very slow—for experienced eyes one can discern what's being

Table 2. User Ratings for Intubation

	MEAN	SD	RANGE
Total no. respondents: 9			
Gender: n (%) male 8 (89%)			
Age	46.4	±6.5	37–58
QUIS results			
3. Overall user reactions to the system			
3.1 1 = terrible–9 = wonderful	7.7	±0.9	7–9
3.2 1 = frustrating–9 = satisfying	7.3	±0.5	7–8
3.3 1 = dull–9 = stimulating	8.3	±0.8	7–9
3.4 1 = difficult–9 = easy	8.3	±0.5	8–9
Overall mean	7.8	±0.6	7.0–9.0
4. Screen			
4.1 Characters on screen: 1 = hard to read–9 = easy to read	6.9	±1.9	3–8
4.2 Highlighting on screen: 1 = unhelpful–9 = helpful	6.8	±2.1	3–9
4.3 Screen layouts helpful: 1 = never–9 = always	7.0	±2.3	2–9
4.4 Sequence of screens: 1 = confusing–9 = clear	6.4	±2.1	3–8
Overall mean	7.2	±1.9	2.8–8.5
10. Multimedia			
10.1 Quality of still pictures/photos: 1 = bad–9 = good	6.9	±1.9	3–9
10.2 Quality of movies: 1 = bad–9 = good	6.0	±1.9	3–8
10.2.1 Focus of movie images: 1 = fuzzy–9 = clear	6.0	±1.4	3–8
10.2.2 Brightness of movie images: 1 = dim–9 = bright	7.3	±1.2	6–9
10.2.3 Window size adequate: 1 = never–9 = always	8.1	±0.8	7–9
10.3 Sound output: 1 = inaudible–9 = audible	7.5	±1.4	5–9
10.3.1 Sound output: 1 = choppy–9 = smooth	6.6	±1.4	5–9
10.3.2 Sound output: 1 = garbled–9 = clear	6.9	±1.2	5–8
10.4 Colors used are: 1 = unnatural–9 = natural	7.1	±1.2	5–9
Overall mean	7.0	±1.0	5.2–8.2
Mean of all items	7.2	±0.8	5.9–8.2

QUIs, Questionnaire for User Interaction Satisfaction.

viewed, but for inexperienced eyes it would be difficult." On the other hand, another evaluator suggests that the "image quality was quite good." The ultrasound viewers may have had variable criteria for success (i.e., low inter-rater reliability), or it is also possible that intermittent technical problems had a greater impact for some sessions but not others. Commonly encountered technical issues were loss of signal and slower than normal transmission intervals. These issues may be attributed to wireless network congestion during testing periods. As the ambulance traveled at speeds up to 65 MPH, it passed through different cells, thus requiring all cellular channels to switch to another tower. During times of peak cellular phone use, some phones did not find an open channel when forced to move between towers. A limitation of this study was that the testing area was selected by comparing typical ambulance travel areas with cellular coverage areas and selecting a zone known to have excellent cellular capabilities. In real situations in rural areas, the cellular coverage may be spotty, introducing blackout zones to the use of this type of system. However, this system uses the commercial cellular infrastructure, which is expanding rapidly and at no additional cost to ambulance crews for expanding this infrastructure. Throughout the evaluation of ultrasound, the ratings for audio quality were much better than for video, indicating that there were not any serious problems with sound during the telemedicine sessions.

The future utility of ultrasound imaging in a mobile telemedicine consult was addressed with the question regarding the use of a Focused Abdominal Ultrasound for Trauma during a teleconsult. One half of our respondents thought the system could be used for this examination, while the other half did not. Not surprisingly, those who answered "Yes" to this final question had much higher scores on QUIS than those who answered "No." The mean of all items was 6.3 (range 4.9–7.2) for the former and the mean of all items was 3.9 (range 2.4–4.9) for the latter. Perhaps further improvements in the compression scheme and increases in aggregate bandwidth will improve the usability of the Focused Abdominal Ultrasound for Trauma examination during a telemedicine consult from a moving ambulance. Whether ultrasound could have a presence on a rural ambulance for trauma, obstetrics, or perhaps cardiology applications is an open question. The clinical utility of such a system would have to be demonstrated. The intent of this study was first to determine *if* it could even be done with our system.

In general, ratings were much higher for the video laryngoscope intubation sequences than for ultrasound, and the range of responses was much narrower. As with ultrasound, video quality was rated as poorer than audio quality, although the quality of images for the intubation appeared to be adequate. In the open comment section, one evaluator noted that "intubation views were superb" and "I could see cords easily. Endotracheal tube outline was fuzzy. I could see stylet when moving—difficult to see until prompted it was being moved."

Of particular interest to our project, evaluators were asked whether the system could be used to telementor intubation. All of our reviewers felt that a physician could assist EMS with the intubation of a patient. However, 89% of respondents also believed audio consultation alone would not be sufficient to aid with the intubation. Although the video laryngoscopy was adequate in "ideal conditions" with a model, secretions in a true telemedicine consult could prove to be a hindrance to image quality, even though the FAST STAR ambulance would have suction equipment similar to that in an emergency room or operating room.

Although this study attempted to duplicate the reality of the clinical situation, this was not a real clinical scenario and any conclusions about whether FAST STAR would actually benefit real patients remains conjectural at this time. Furthermore, improvements in transmission technology may make FAST STAR more attractive as a clinical tool in the management of the rural trauma patient.

Our next step in evaluating peripheral equipment in a telemedicine consult should address the concern of video image quality. This study clearly provides evidence that telemedicine may provide an advanced support mechanism for rural EMS personnel and patients, although our system may be better suited for intubation than for ultrasound use.

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