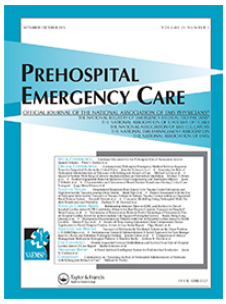

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Feasibility of Paramedic Performed Prehospital Lung Ultrasound in Medical Patients with Respiratory Distress

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Abstract

Objective: Prehospital ultrasound is not yet widely implemented. Most studies report on convenience samples and trauma patients, often by prehospital physicians or critical care clinicians. We assessed the feasibility of paramedic performed prehospital lung ultrasound in medical patients with respiratory distress. **Methods**: Paramedics at 2 ambulance stations in the city of Pittsburgh, Pennsylvania, USA underwent a 2-hour training session in prehospital lung ultrasound using the SonoSite iViz, a handheld ultrasound device. Emergency medical services (EMS) command center (EMS-CC) physicians were instructed in the interpretation of lung ultrasound images. Paramedics enrolled patients presenting with signs and symptoms of respiratory distress over a 3-month period. The ultrasound exam included anterior and lateral views from both sides of the chest. Images were transmitted wirelessly using a mobile hotspot device and uploaded into an online image archiving system. Images were interpreted remotely by the EMS-CC physicians, and 2 expert sonographers provided an overread. We assessed agreement between EMS-CC physicians and experts, as well as between chart-review derived ED diagnosis and both EMS-CC physician and expert interpretation. We defined four *a priori* hypotheses that would need to be met for the intervention to be considered "feasible." **Results**: A total of 34 of 78 (43.6%) eligible patients had an ultrasound exam completed. Image transmission was successful in 25 (73.5%) of cases where ultrasound was performed. The primary reason for not enrolling an otherwise eligible patient was equipment failure (25.0%), followed by patient acuity and patient refusal (18.2% each). A total of 20 (58.8%) completed scans were deemed uninterpretable upon expert review. Agreement between EMS physicians and experts was poor. Agreement between EMS-CC physicians and ED diagnosis, as well as between experts and ED diagnosis, was fair. The predetermined thresholds for feasibility were not met. **Conclusions**: Paramedic performed prehospital lung ultrasound for patients with respiratory distress and remote interpretation by EMS physicians did not meet the predetermined thresholds to be considered "feasible" in a real-world environment with currently available technologies. This study identified important barriers to the implementation of prehospital lung ultrasound, which should be addressed in future studies. **Key words**: ultrasonography; emergency medical services; ambulances; dyspnea; telemedicine

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Introduction

Patients with undifferentiated respiratory distress are a diagnostic challenge for emergency clinicians. The etiology of a patient's symptoms is often difficult to ascertain early on. In the Emergency Department (ED), point-of-care ultrasound (POCUS) is increasingly used to quickly narrow the differential diagnosis.

For many patients with respiratory distress, emergency medical services (EMS) is the first point of contact with the medical response system. The evaluation of patients with respiratory distress in an ambulance is made even more challenging than in the ED due to multiple factors. Consequently, many patients with respiratory distress will receive combination treatments, aimed at treating the most common causes, simultaneously. The use of POCUS in the EMS setting thus far has been limited, with most advanced applications done in physician-staffed helicopter EMS systems.[1,2] In this study, we assessed the feasibility of paramedic performed, remotely interpreted prehospital ultrasound in medical patients with undifferentiated respiratory distress.

Methods

Study Design and Setting

This was a prospective observational study of prehospital ultrasound in patients with respiratory distress. Patients who were cared for by paramedics from 2 ambulance stations in the city of Pittsburgh, Pennsylvania, USA, were enrolled over a 3-month period based on device availability and expected patient volume. Paramedics were to enroll all patients who

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complained of shortness of breath and/or who had objective signs of respiratory distress and/or who had a non-invasively measured oxyhemoglobin concentration (SpO2) of <92%. Patients were excluded if they were <18 years of age, pregnant, prisoners, trauma patients, or chronically on home oxygen without new respiratory complaints. We excluded trauma patients because the differential diagnosis is usually much more complex in medical patients with respiratory distress. This study was approved by the Institutional Review Board of the University of Pittsburgh.

Protocol, Measurements, and Key Outcomes

All paramedics working at the 2 ambulance stations included in this study were trained in lung ultrasound images using a SonoSite iViz handheld ultrasound device (SonoSite, Bothell, WA, USA). The training consisted of a 30-min lecture, followed by hands-on practice for a total duration of 2 hr and was based on previous studies demonstrating appropriate skill achievement in lung ultrasound after a brief training.[3–5] A refresher-training was held 6 days before study start. All paramedics also received a written summary of the steps involved in successfully completing the scanning procedure, and a video demonstration was available online as an additional resource.

The scanning procedure was performed with a phased array probe, at a depth set to at least 16 cm, starting in the right midclavicular line from the clavicle down along the chest wall over 10 sec, followed by a scan in the mid-to-posterior axillary line laterally, also moving the probe caudally over 10 sec. This was then repeated on the left side. A depth of 16 cm was required to differentiate extravascular lung water from other artifacts. Paramedics also completed a survey asking them for their gestalt assessment of "dry" vs. "wet" lungs, which was then transcribed as a corresponding ultrasound lung profile (A profile = normal lungs and obstructive lung disease, B profile = pulmonary edema or multifocal pneumonia, AB profile = pneumonia or acute respiratory distress syndrome).[6,7] After the exam, the device automatically connected to a mobile hotspot device (T-Mobile, Bellevue, WA, USA) and transmitted anonymized images to an online imaging archiving system (Trice Medical Imaging Company, Del Mar, CA, USA). Images were accessed daily by the Pittsburgh EMS command center (EMS-CC) physician on duty who interpreted the studies. All EMS-CC physicians had received training in the interpretation of lung ultrasound through an online video lecture (which was available on demand throughout the study period) and an optional in-person lecture. The EMS-CC physicians reported each cine clip separately as predominance of A lines, B lines or uninterpretable, which was then compiled into a corresponding lung profile.[6]

Table 1. *A priori* defined hypotheses that would support feasibility of prehospital lung ultrasound

Hypothesis 1: Paramedics can obtain adequate images.
Test 1: Paramedics will attempt to obtain images in >80% of eligible cases.
Test 2: Paramedics will successfully obtain images in >80% of attempted cases.
Test 3: Expert sonographers will deem >80% of images that are obtained to be interpretable.
Hypothesis 2: Images can be transmitted in real-time.
Test: Image transmission will be successful in >80% of scans performed.
Hypothesis 3: EMS-CC physicians can interpret field images reliably.
Test: Agreement between expert sonographer interpretation and EMS-CC physician interpretation will be >0.5.
Hypothesis 4: This information will be clinically useful.
Test: Ultrasound images will correlate with the ED diagnosis in >80% of patients.

EMS-CC: *emergency medical services command center*; ED: *emergency department*.

After enrollment concluded, all ultrasound scans were reviewed by 2 expert sonographers who provided a consensus expert over-read as criterion standard. The expert sonographers had extensive training and experience in POCUS, including over 1000 lung scans each, and exceeded the "Emergency Ultrasound Fellowship Guidelines" set by the American College of Emergency Physicians.[8] We also performed a blinded chart review of patients admitted to a University of Pittsburgh Medical Center-affiliated hospital and recorded a standardized ED diagnosis, along with a presumptive lung profile associated with this diagnosis.

We defined four *a priori* hypotheses through consensus among the investigators for the intervention to be considered "feasible" (Table 1). Based on data from initial studies evaluating prehospital 12-lead electrocardiogram transmission, we set a threshold of 80% for hypotheses 1 and 2.[9]

As this was a feasibility trial, neither the paramedics nor the EMS-CC physicians altered patient care decisions based on ultrasound findings.

Analytical Methods

Data were analyzed using descriptive and inter-rater agreement statistics using R version 3.3.1 (R Core Team).[10] Cohen's Kappa was assessed for inter-rater agreement, categorized from "poor" to "almost perfect" as per Landis and Koch criteria.[11]

Results

Seventeen paramedics completed the training. Out of 78 eligible patient encounters, 34 (43.6%) patients had the ultrasound exam completed. All enrolled patients

TABLE 2. Reasons provided by paramedics for not having enrolled an otherwise eligible patient

Reason	$n = 44$, %
Equipment failure	11 (25%)
Patient condition too critical	8 (18.2%)
Patient refusal	8 (18.2%)
Transport time too short	6 (13.7%)
Other/no details given	6 (13.7%)
Lack of training	5 (11.4%)

had all 4 cine clips obtained successfully. Because of software problems, image transmission was successful for only 25 (73.5%) completed exams.

The primary reason reported by the paramedics for why a scan was not performed on an otherwise eligible patient was equipment failure, mostly due to insufficient battery charge (Table 2). Lack of training was reported for 5 (11.4%) missed encounters, as a few new paramedics had been assigned to the participating ambulance stations during the study period; they did not complete the ultrasound training.

Twenty out of 34 (58.8%) scans were deemed uninterpretable, 15 due to insufficient quality, and 5 due to inappropriate depth. Agreement between expert and the EMS-CC physician interpretation was poor (Cohen's Kappa of 0.167).

ED data were available for 15 patients (Table 3). Agreement between the ED diagnosis-derived lung profile and EMS-CC physicians was fair (0.385). Agreement between the ED diagnosis-derived lung profile and the expert sonographers' interpretation was also fair (0.306). Five out of 8 (62.5%) interpretable scans read by the expert sonographers correlated with the ED diagnosis. Paramedic clinical gestalt showed good agreement with the ED diagnosis-derived lung profile (Cohen's Kappa of 0.774).

DISCUSSION

This study was a methodologically rigorous attempt to assess the feasibility of prehospital ultrasound in a "real-world test," based on *a priori* defined hypotheses (Table 1). Previous studies of prehospital ultrasound suffer from a high risk of bias.[12] With the exception of the number of successfully obtained images in attempted cases, none of the pre-defined feasibility thresholds were met.

These findings reflect a variety of challenges. Software deficiencies and insufficient battery capacity limited enrollment and image transmission. In many cases, paramedics deemed patient acuity too high or transport time too short to complete an exam.

Many images obtained by paramedics were deemed of insufficient quality on expert review. Images were frequently overgained and thus "too bright," presumably due to glare from the device's display and insufficient image contrast.

The difficulties faced with the image transmission call into question whether images should be interpreted remotely by a medical oversight physician, and our approach to this may have been overly cautious. Interpretation by paramedics at the point-of-care may be advantageous, and has previously been shown to be reliable.[13–15] We aimed to first evaluate the feasibility of image acquisition in the field, without confounding the challenges of training and image

TABLE 3. Emergency department diagnoses, paramedic clinical gestalt, and associated ultrasound findings

Patient	Standardized ED diagnosis	Lung profile typically associated with this diagnosis	Paramedic gestalt "lung profile"	EMS-CC physician lung profile interpretation	Expert sonographer lung profile interpretation
1	Pneumonia	AB	AB	X	AB
2	Uncertain	n/a	Uncertain	A	X
3	ADHF	B	A	X	X
4	COPD	A	A	A	X
5	ADHF	B	B	A	A
6	Non-respiratory	A or AB	A	AB	A
7	Pneumonia	AB	AB	X	X
8	Non-respiratory	A or AB	A	AB	AB
9	Pneumonia	AB	A	AB	A
10	COPD	A	A	AB	A
11	Non-respiratory	A or AB	A	A	A
12	Pneumothorax	A[†]	A	–[*]	X
13	Uncertain	n/a	Uncertain	–[*]	X
14	COPD	A	A	–[*]	AB
15	COPD	A	A	–[*]	X

ED: *Emergency Department*; EMS-CC: *Emergency Medical Services Command Center*; ADHF: *acute decompensated heart failure with pulmonary edema*; COPD: *chronic obstructive pulmonary disease*; A: *A lung profile*; B: *B lung profile*; AB: AB lung profile;

[*] not available due to transmission unsuccessful; X = uninterpretable due to poor quality images.

[†] = pneumothorax is diagnosed on ultrasound by absence of lung sliding

interpretation by clinicians that have not previously used ultrasound. In future studies, we need to determine whether on-site interpretation by paramedics can reliably overcome the challenges of image transmission to achieve an accurate diagnosis. We also need to explore further the poor inter-rater agreement in exam interpretation between experts and EMS-CC physicians, to determine whether training, format or other factors can improve reliability.

In summary, our study can be considered a gap analysis that successfully revealed factors limiting the implementation of prehospital ultrasound with currently available technologies ((16,17): 1) technical limitations with currently existing ultrasound devices, such as battery life, display, software and data transmission; 2) image acquisition in practice, considering both training and environmental aspects; and 3) remote interpretation, distinctly different from the usual practice of POCUS by emergency physicians, and the additional training that may be required.

LIMITATIONS

It is conceivable that more extensive training would enable paramedics to obtain higher quality images. Similarly, more training for the EMS-CC physicians may have improved the reliability of their interpretations.[4] Our study was conducted in an urban EMS system with short transport times. Rural EMS may have more time to complete ultrasound exams during longer transports. About 18% of eligible patients who did not have an ultrasound performed refused the exam, we did not explore why. Any conclusion based on the small number of ED data should be considered preliminary.

CONCLUSION

Paramedic performed prehospital lung ultrasound for patients with respiratory distress and remote interpretation by EMS physicians did not meet *a priori* defined thresholds for feasibility. We identified important barriers to the implementation of prehospital lung ultrasound.

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