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ORIGINAL RESEARCH

Imaging

Drowning rule-out with novices (DROWN) in ultrasound

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Abstract

Objectives: Non-fatal drownings confer significant morbidity and mortality in the United States. Chest radiograph (CXR) is typically used as a screening modality for interstitial edema but lacks sensitivity early after submersion. No study has evaluated lung ultrasound in assessing for pulmonary edema after submersion events and we hypothesized that lung point-of-care (POC) ultrasound can identify interstitial edema in patients presenting after non-fatal drownings.

Methods: Patients presenting to the emergency department after a submersion event were eligible if a CXR was obtained as part of their care. Emergency medicine residents performed a lung POC ultrasound and provided a "novice" interpretation of "normal" or "abnormal," which was independently reviewed by a blinded expert sonographer. Patients were contacted 2 weeks after presentation to assess for late sequela.

Results: A prospective convenience sample of 59 patients included 21 adults (36%) and 38 children (64%) enrolled over 17 months with a median age of 6. Twenty-four (41%) patients had abnormalities on CXR. Of these, 20 patients had a positive ultrasound per novice interpretation. Compared to CXR, ultrasound had an overall sensitivity of 83% and a specificity of 66% for detecting pulmonary edema in non-fatal drownings. Notably, out of 35 subjects with a negative CXR, there were 12 (34%) cases with a positive lung ultrasound, 10 of which required hospital admission.

Conclusion: Lung POC ultrasound has a moderate sensitivity and specificity when performed by novice sonographers to detect pulmonary edema presenting to an ED setting after a non-fatal drowning event.

KEYWORDS
emergency medicine, near drowning, point-of-care, ultrasound

1 | INTRODUCTION

1.1 | Background

Drowning is one of the leading causes of death in the United States, especially among children less than 4 years old with nearly 4000 drowning deaths each year.[1] Despite the high prevalence of drowning incidents, there is contention regarding the management and ultimate disposition of victims presenting to emergency departments.[2] Non-fatal drowning victims may initially present with a normal examination, only to later develop conditions such as acute respiratory distress syndrome, hypoxemia, and pulmonary edema.[3–4]

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1.2 | Importance

Chest radiography (CXR) of these patients at the time of their presentation cannot always reliably detect life-threatening pulmonary injuries, nor can they predict a patient's likelihood of deterioration.[5–8] When comparing the sensitivity and specificity of bedside ultrasound to CXR to identify pulmonary edema, Wooten et al. found that ultrasound had a significantly higher sensitivity (96% vs 65%).[9] Because of the difficulty in predicting which patients will clinically decompensate after a submersion event, publications regarding emergency management recommend that victims of non-fatal drownings remain in a monitored setting for up to 8 hours after the event.[3,4,10,11]

Multiple studies have demonstrated the utility of B-lines, a type of vertical artifact on pulmonary ultrasound, to identify the presence of alveolar fluid.[12–15] B-lines indicate disruptions to the lungs' gas-tissue interface with greater accuracy than conventional CXR and such can diagnose pulmonary edema according to the Bedside Lung Ultrasound in Emergency (BLUE) protocol.[16] Emergency physicians can determine potential etiologies of acute respiratory failure using the BLUE protocol with 90.5% accuracy in <5 minutes.[16,17] When applied in an emergency department setting, the BLUE protocol remains suitable for differentiating underlying pathologies leading to dyspnea and reduce the time needed to deliver definitive treatments.[18–21]

1.3 | Goals of this investigation

Previous studies have evaluated the ability of lung ultrasound to identify the presence of alveolar fluid that develops from intrinsic processes, such as congestive heart failure; however, none have investigated the use of ultrasound to identify alveolar fluid that results from an extrinsic process, such as a drowning event. This study sought to investigate the accuracy of lung point-of-care (POC) ultrasound performed by novice scanners to identify pulmonary edema in patients presenting to an ED setting after a non-fatal drowning event. We also aimed to compare the performance of lung POC ultrasound to CXR with regard to the presence or absence of pulmonary edema.

2 | METHODS

2.1 | Study design and setting

This was a single-center, prospective study performed at an academic, tertiary care, level 1 trauma center in Myrtle Beach, SC, with over 120,000 patient encounters per year. The study underwent institutional review board approval (IRB protocol #2018-064).

2.2 | Selection of participants and exposures

Eligibility included patients of any age who presented to the ED after a submersion injury of any type and received a CXR as part of their evaluation as determined by the ED care team. The only exclusion criteria were patients who presented in cardiac arrest but the return of spontaneous circulation was not achieved, and anyone who declined to participate in the study. All subjects consented to participation. The water type was considered "salt" if the submersions occurred in the ocean with all other submersions being classified as "fresh."

The Bottom Line

The role of lung ultrasound in submersion victims has not been well researched. This study found that lung ultrasound performed by novices compared favorably to standard chest radiography (in fact, even better in some cases). This study is important because not only does it confirm the value of early lung ultrasound in the emergency department for submersion victims, but it also shows that it is an easy skill to learn.

2.3 | Measurements

Eligible patients underwent lung POC ultrasound performed by emergency medicine residents who were not involved in the patient's care and had basic training in lung ultrasound technique and B-line identification. All residents received equivalent training on lung POC ultrasound, which included conference didactic sessions covering the basic applications of lung ultrasound, a dedicated emergency ultrasound rotation during the second-year curriculum, and frequent clinical bedside patient scanning with 100% POC ultrasound studies submitted to our middleware system undergoing quality assurance review and feedback by emergency medicine faculty with emergency ultrasound fellowship training. The residents performing the ultrasound were instructed to blind the treating team to the ultrasound results unless they felt the ultrasound would change immediate clinical care (eg, identification of a pneumothorax). The lung field between 2 adjacent ribs was examined at a total of 8-points along the thorax at approximately the third and sixth intercostal spaces along the midclavicular and midaxillary lines bilaterally. Sonographs were obtained under grayscale B-mode using either a 1–5 MHz convex array probe for adults and older children or a 3–12 MHz linear array probe for infants and smaller children. Most studies were captured using the GE Venue (GE Healthcare, Chicago IL, USA) with a minority of studies performed using a SonoSite Edge (FUJIFILM Sonosite, Inc, Bothell, WA, USA). Studies were considered abnormal if 3 or more B-lines were present in any lung field.

The resident provided a "novice" interpretation of their scan as either normal or abnormal and was blinded to the CXR results. The novice's interpretation was later compared to the interpretation of the subject's CXR provided by board-certified radiologists, which served as the "gold standard" to obtain statistical data. Any pathology noted in the radiologist's interpretation of the radiograph was considered a true positive result.

Ultrasound clips were stored in a middleware cloud-based software program, QpathE (Telexy Healthcare, Blaine, WA, USA), and later reviewed by the emergency medicine ultrasound director, who provided a blinded expert interpretation for comparison to the novices' interpretation while also ensuring scan quality. We also attempted to contact all patients via phone 2 weeks after the submersion event to assess for any complications after discharge from either the ED or hospital for those who were admitted.

2.4 | Data analysis

For the primary analysis, we compared lung POC ultrasound to CXR using sensitivity and specificity with a 95% confidence interval (CI) using CXR as the gold standard for all patients, which was further stratified by age and disposition status using descriptive statistics. Sensitivity and specificity were calculated based on naïve measures without mathematical adjustments using Statistica 13 (TIBCO, Inc., Palo Alto, CA) and R statistical software (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was determined using $\alpha = 0.05$. Agreement between novices and expert interpretations was evaluated using Cohen's Kappa coefficient using R statistical software and the "irr" package.

3 | RESULTS

3.1 | Participant characteristics

A total of 59 patients were enrolled from April 2019 through September 2020 (Table 1). Results were calculated using all subjects. The median age of all subjects was 6 years old (range 2–64 years), with 66% being male. Adults were considered patients 18 years of age or older. Most patients were visitors to the area, with 81% reporting an address of at least 60 miles outside of Myrtle Beach, SC. The median time underwater was 120 seconds (interquartile range 30–300) for adults and 30 seconds (interquartile range 15–120) for children. Seven (33.3%) adults and 10 (26.3%) children received bystander cardiopulmonary resuscitation. A total of 25 different residents performed the scans with 1 resident completing 7 of the scans. The residents averaged 9 previously completed and submitted pulmonary ultrasounds.

Most subjects were admitted to the hospital, including 16 adults (76.2%) and 20 children (52.6%). Of those who were admitted, 15 adults (93.8%) and 19 children (95%) survived to discharge. The average time from submersion event to ultrasound was approximately 80 minutes, with 9 patients being excluded from these data due to the lack of available documentation regarding the time of submersion. The average time between obtaining the POC ultrasound and CXR was 39 minutes. One patient was excluded from this data because the ultrasound was performed approximately 12 hours after admission the following morning; however, both the CXR and ultrasound were interpreted to be abnormal.

Of note, we initially calculated a need to enroll 71 patients to determine the statistical significance between ultrasound and CXR; however, the study data were analyzed at the completion of the tourist season in 2020 with 59 subjects largely due to restrictions on prospective enrollment and other limitations imposed by the COVID-19 pandemic.

3.2 | Primary outcome

When performed and interpreted by the novice group, lung POC ultrasound had an overall sensitivity of 83.3% (95% CI, 0.62–0.95) and specificity of 65.7% (95% CI, 0.47–0.81) for the detection of pulmonary edema after non-fatal drowning events (Table 2). When compared to the expert interpretation, overall sensitivity decreased to 70.8% (95% CI, 0.49––0.87), but specificity increased to 71.4% (95% CI, 0.54–0.85) (Table S1).

Lung POC ultrasound performed best in ruling out pulmonary edema in all subjects who were safely discharged from the ED, with a novice specificity of 90.0% (95% CI, 0.68–0.97) (Table 2). There were not any discrepancies between novice and expert interpretations of the discharged patients' ultrasounds.

For admitted adults, novice sensitivity improved to 87.5% (95% CI, 0.47–0.99), but specificity decreased to 33.3% (95% CI, 0.12–0.62). Expert result analysis differed for this population, with a sensitivity of 71.4% (95% CI, 0.48–0.89) and a specificity of 46.7% (95% CI, 0.21–0.73) (Table S1).

3.3 | Secondary outcomes

Analysis of novice performance on lung POC ultrasound interpretation compared to the expert found an 81.4% match (95% CI, 0.69–0.90) of normal versus pathologic (Table 3). The novices were much more likely to interpret a scan as pathologic, as there were 8 cases (25.0%) when a novice interpreted a scan as abnormal, but the expert ultimately called it normal. This is compared to 3 cases (11.1%) where the novice felt the scan to be normal, but the expert interpreted the scan to have an abnormal B-profile. All 3 of these patients had negative CXR interpretations and 2 out of these 3 patients were admitted to the hospital.

No patient we contacted 2 weeks after being discharged from the ED reported any clinically significant complications related to the submersion event; however, response rates were very limited at approximately 50%.

4 | LIMITATIONS

The largest limitation of this study was the lack of an accurate gold standard to compare against the ultrasound findings. Computed tomography scan of the chest would have been preferred but is not

TABLE 1 Patient characteristics.

All emergency department patients	Overall (*n* = 59)	Adult (*n* = 21)	Child (*n* = 38)
Age			
Median (IQR)	6.0 (3.0–33.0)	49.0 (31.0–64.0)	3.5 (2.0–6.0)
Mean (SD)	20.9 (24.7)	49.9 (19.3)	4.9 (4.0)
Gender			
Female	20 (33.9)	5 (23.8)	15 (39.5)
Male	39 (66.1)	16 (76.2)	23 (60.5)
Race			
Black	14 (23.7)	3 (14.3)	11 (29.0)
White	34 (57.6)	14 (66.7)	20 (52.6)
Other	11 (18.7)	4 (19.0)	7 (18.4)
Residency			
Local	10 (18.0)	3 (14.3)	7 (18.4)
Not local	48 (81.3)	17 (81.0)	31 (81.6)
Unknown	1 (1.7)	1 (4.7)	0 (0.0)
Time underwater (sec)			
Median (IQR)	30.0 (20.0–120.0) *(n = 53)*	120.0 (30.0–300.0) *(n = 16)*	30.0 (15.0–120.0) *(n = 37)*
Mean (SD)	115.3 (163.7) *(n = 53)*	177.8 (168.0) *(n = 16)*	88.3 (156.4) *(n = 37)*
Water type			
Fresh	37 (62.7)	5 (23.8)	32 (84.2)
Salt	22 (37.3)	16 (76.2)	6 (15.8)
Arrival GCS			
Severe (8 or less)	5 (8.5)	4 (19.0)	1 (2.6)
Moderate (9–12)	1 (1.7)	1 (4.8)	0 (0.0)
Mild (13–15)	53 (89.8)	16 (76.2)	37 (97.4)
Bystander CPR			
No	42 (71.2)	14 (66.7)	28 (73.7)
Yes	17 (28.8)	7 (33.3)	10 (26.3)
ED disposition			
Admitted	36 (61.0)	16 (76.2)	20 (52.6)
Discharged	23 (39.0)	5 (23.8)	18 (47.4)
Patients admitted from the ED	**Overall (*n* = 36)**	**Adult (*n* = 16)**	**Child (*n* = 20)**
Change in respiratory support^	*(n = 34)*	*(n = 16)*	*(n = 18)*
No change	9 (26.5)	2 (12.5)	7 (38.9)
De-escalation	22 (64.7)	13 (81.3)	9 (50.0)
Escalation	3 (8.8)	1 (6.2)	2 (11.1)
Required intubation			
No	30 (83.3)	11 (68.8)	19 (95.0)
Yes	6 (16.7)	5 (31.2)	1 (5.0)
Hospital length of stay (hours)			
Median (IQR)	24.0 (15.5–39.0)	42.0 (24.0–84.0)	16.8 (13.0–24.0)
Mean (SD)	41.8 (68.2)	71.2 (95.6)	18.3 (7.6)
Survived to hospital discharge (*n* = 35)			(*n* = 19)
Alive	34 (94.4)	15 (93.8)	19 (95)
Died	2 (5.5)	1 (6.2)	1 (5)
Patients discharged from the ED	**Overall (*n* = 23)**	**Adult (*n* = 5)**	**Child (*n* = 18)**
Reported complications after discharge			
No	10 (43.5)	0 (0.0)	10 (55.6)
Yes	1 (4.3)	1 (20.0)	0 (0.0)
Unknown	12 (52.2)	4 (80.0)	8 (44.4)

Abbreviations: CPR, cardiopulmonary resuscitation; ED, emergency department; IQR, interquartile range.

TABLE 2 Novice sensitivity and specificity of lung ultrasound versus chest x-ray.

Overall (*n* = 59)	Chest x-ray (+)	Chest x-ray (-)	Sensitivity (95% CI)	Specificity (95% CI)	Cohen's K (95% CI)
Ultrasound (+)	20	12	83.3% (0.62–0.95)	65.7% (0.48–0.81)	0.47 (0.22–0.72)
Ultrasound (–)	4	23			
Adult (*n* = 21)	**Chest x-ray (+)**	**Chest x-ray (–)**	**Sensitivity (95% CI)**	**Specificity (95% CI)**	**Cohen's K (95% CI)**
Ultrasound (+)	7	7	87.5% (0.47–0.98)	46.2% (0.19–0.75)	0.29 (–0.08–0.66)
Ultrasound (–)	1	6			
Child (*n* = 38)	**Chest x-ray (+)**	**Chest x-ray (–)**	**Sensitivity (95% CI)**	**Specificity (95% CI)**	**Cohen's K (95% CI)**
Ultrasound (+)	13	5	81.3% (0.54–0.96)	77.3% (0.55–0.92)	0.58 (0.27–0.89)
Ultrasound (–)	3	17			
Discharge (*n* = 23)	**Chest x-ray (+)**	**Chest x-ray (–)**	**Sensitivity (95% CI)**	**Specificity (95% CI)**	**Cohen's K (95% CI)**
Ultrasound (+)	2	2	66.7% (0.09–0.99)	90.0% (0.68–0.97)	0.50 (0.09–0.91)
Ultrasound (–)	1	18			
Admit (*n* = 36)	**Chest x-ray (+)**	**Chest x-ray (–)**	**Sensitivity (95% CI)**	**Specificity (95% CI)**	**Cohen's K (95% CI)**
Ultrasound (+)	18	10	85.7% (0.64–0.97)	33.3% (0.12–0.62)	0.20 (–0.09–0.49)
Ultrasound (–)	3	5			

Abbreviation: CI, confidence interval.

TABLE 3 Novice versus expert agreement analysis.

	Novice vs expert
# Assessed	59
# Matched	48
% Matched (95% CI)	81.36 (0.69–0.90)
Kappa–response = 1 (normal)	0.63
Kappa–response = 2 (abnormal)	0.63

Note: There were 3 cases (11.11%) when novice responded normal, and expert abnormal. Also, there were 8 cases (25.00%) when novice responded abnormal and expert responded normal.
Abbreviation: CI, confidence interval.

routinely used in submersion patients, especially given the strong predominance of pediatric drownings and the need to limit radiation. Prior studies have shown that sonography is equal to, if not better than, plain radiography at identifying pulmonary edema from intrinsic etiologies; however, this has not been confirmed for extrinsic etiologies of pulmonary edema, such as drowning, which prevented us from using the ultrasound expert's interpretation as our gold standard for which to compare the novice interpretation.[22,23] It is likely that ultrasound would have better test characteristics if compared to a true gold standard.

Additionally, we did not account for baseline abnormalities that could be seen on POC ultrasound or CXR. The presence of preexisting pathology in our local and tourist population makes it possible that CXR and/or POC ultrasound would be abnormal despite the subject's non-fatal drowning. We also included any abnormality on CXR interpretation to be a "true positive" and it is certainly possible that not all true positive CXRs had clinically significant findings and could have falsely reduced the sensitivity of lung POC ultrasound.

Subject selection, response, and attrition biases were also confounding variables. Enrollment was a convenience sample and favored times when study investigators were present in the department, which was most often weekdays during the day shift. Additionally, many potential subjects were lost due to the sensitive and emotional nature of their submersion event, causing the family members to decline enrollment. Unfortunately, this data was not tracked and therefore cannot be reported as a Standards for Reporting of Diagnostic Accuracy Studies diagram. Also, approximately half of our discharged patients were lost to follow-up and could have presented to other medical facilities for complications making it difficult to confirm that patients discharged in the setting of a negative ultrasound did not experience late sequela of their non-fatal drowning event.

5 | DISCUSSION

Our study demonstrated a modest *overall* sensitivity of 83% and specificity of 65% for the POC ultrasound detection of pathologic B-lines after a non-fatal drowning event when compared to CXR. When disposition and extent of lung injury were considered, it performed better in subgroup analysis. In patients who required *admission*, POC ultrasound showed a higher sensitivity of 88%. For patients presenting with signs of acute decompensated heart failure, lung ultrasound consistently outperformed CXR in terms of sensitivity and specificity for the detection of *cardiogenic* pulmonary edema. A large systematic review and meta-analysis found that the sensitivity of lung POCUS was 91.8% and specificity was 92.3%, higher in both cases than CXR for cardiogenic pulmonary edema detection.[24] Our findings were less robust and in a different patient population, but in terms of clinical significance, we found concordance with regard to POC ultrasound specificity in low-risk drownings. POCUS performed best in identifying patients without pulmonary edema, with a specificity of 90% in patients who were ultimately *discharged* from the ED. This supports the notion that patients who appear clinically well and have no pathologic B-lines on lung POC ultrasound do not have a clinically significant pulmonary injury related to their non-fatal drowning event.

When compared to an expert sonographer's interpretation of the lung POC ultrasound exams, there was a general decrease in sensitivity but an increase in specificity (Table S1). The exceptions were consistent results between the novice and expert for adult sensitivity at 87% and 88%, respectively, and pediatric specificity, both of which were 77%. It is likely that the novice was more inclined to interpret a true negative study as pathologic because they had a degree of awareness regarding the clinical situation due to the reality of being at the patient's bedside, whereas the expert was blinded to this information. Also, it has been our experience that a novice is more likely to call a study abnormal when they are unsure of the clinical significance of certain normal and abnormal findings, such as the presence of A-lines, subpleural consolidations, among others.

Notably, we did find 7 POCUS positive and CXR negative cases in patients who had a new supplemental oxygen requirement and were admitted for supportive care after their submersion event (Video S1). This is suggestive that lung POC ultrasound may be more sensitive in the detection of pulmonary edema in the early stages after a submersion event. Does the timing of the lung scan matter? Little is known about the progression and the performance of lung POC ultrasound for non-cardiogenic pulmonary edema detection in drowning victims.

Do age, body surface area, and comorbidities play a role? A systematic review and meta-analysis evaluating lung POC ultrasound's performance for pulmonary edema detection in critically ill children again supported improved sensitivity and specificity over CXR.[25] Our very small pediatric cohort supported these findings when extrapolated to drowning victims (Table 2). Given the relative ease and availability of POC ultrasound, further investigation in pediatric drownings is both feasible and necessary.

To the authors' knowledge, this is the only study that has investigated the use of pulmonary POC ultrasound to evaluate for lung injury in a non-fatal downing cohort. Although many limitations exist, we found evidence to support the use of lung POC ultrasound to determine the presence of pulmonary edema in patients presenting to the ED after submersion events. Our results even more strongly supported the use of lung POC ultrasound to rule out pulmonary edema in non-fatal drownings. These results should be taken as hypothesis-generating and require further studies before changing clinical practice. Future studies employing a true gold standard are needed to determine the true test characteristics for lung POC ultrasound to both rule in and rule out pulmonary edema in non-fatal drowning subjects.

AUTHOR CONTRIBUTIONS

Stewart Russ Richardson: Data collection and interpretation, manuscript drafting. Jacob Pope: Manuscript drafting and editing. Leslie B. Hart: Statistical expertise and data interpretation. Casey L. Wilson: Manuscript drafting and editing

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Stephen Sandelich, MD: Study concept. Spencer Masiewicz, DO: Data collection. Lexus Dixon: Data collection.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DISCLAIMER

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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