OPEN

Impact of Point-of-Care Ultrasound in the Emergency Department on Care Processes and Outcomes in Critically Ill Nontraumatic Patients

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Objectives: Outcomes data on point-of-care ultrasound (POCUS) in critically ill patients are lacking. This study examines the association between POCUS in the emergency department and outcomes in critically ill patients.

Design: Retrospective cohort study of critically ill emergency department patients in two academic emergency departments. All emergency department patients admitted to the intensive care unit or that die in the emergency department were entered prospectively into a registry.

Setting: Two academic emergency departments.

Patients: All adult (> 18 years old) non-trauma patients with hemodynamic instability [shock index (heart rate/systolic blood pressure) > 0.6] between November 1, 2013-October 31, 2016, were included.

Interventions: Cohorts were assigned as follows: no POCUS (cohort 1), POCUS prior to a key intervention (cohort 2), and POCUS after a key intervention (cohort 3). A key intervention was either a fluid bolus or vasoactive drug initiation.

Measurements and Main Results: Multivariable logistic regression was used to evaluate the association between POCUS use and the primary outcome of in-hospital mortality. We conducted several sensitivity analyses including propensity score matching and inverse-probability-weighted regression-adjustment along with multiple imputation to account for non-random assignment of POCUS as well as bias due to missing data. Of the 7,734 eligible patients, 2,293 patients were excluded. The remaining 5,441 patients were included in the analysis: 4165 in Cohort 1, 614 in Cohort 2, and 662 in Cohort 3. Mortality was 22%, 29%, and 26%, respectively ($p < 0.001$). POCUS prior to an intervention was associated with an adjusted odds ratio for death of 1.41 (95% CI, 1.12-1.76) compared to no POCUS. The sensitivity analyses showed an absolute increased mortality of +0.05 (95% CI, 0.02-0.09) for cohort 2 compared to 1.

Conclusions: POCUS use prior to interventions appears to be associated with care delays and increased in-hospital mortality compared to critically ill patients with no POCUS. Further explorations of the impact of POCUS in the emergency department appear warranted.

Key Words: critical care; emergency department; point-of-care ultrasound; shock; ultrasound

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Hypotension and shock in the emergency department (ED) is associated with increased mortality (1). Early recognition and appropriate treatment of patients in shock decreases this mortality substantially (2, 3). The priorities in the ED include restoration of intravascular volume, infusion of vasopressors, and respiratory support. Yet, both inadequate and over-resuscitation have been shown to be associated with a higher risk of

mortality (3–15), which has led to debate over the individual components of resuscitation. This is particularly true for fluid resuscitation, where debate exists over determining volume responsiveness, fluid tolerance, the optimal resuscitation fluid (16–25).

Traditionally, invasive monitoring of cardiac filling pressures and cardiac output were used to guide resuscitation. These invasive measures have faded due to lack of correlation with volume responsiveness (26, 27) and potentially harmful patient outcomes (28). Point-of-care ultrasound (POCUS) is now widely available in the ED and ICU and provides easily obtainable noninvasive evaluations of cardiopulmonary function. In an uncontrolled before and after study, POCUS shortened ED length-of-stay, reduced time to laboratory testing, and reduced time to completion of CT imaging in critically ill patients (29). POCUS performed on hypotensive patients presenting to the ED is considered an appropriate diagnostic tool to aid in the preliminary diagnosis (30, 31). POCUS in patients with hypotension or shock has been reported to reduce diagnostic uncertainty and has potential to guide resuscitation (31–35); however, outcomes data are lacking. The objective of this study was to examine the association between POCUS and outcomes in critically ill nontraumatic ED patients. Our hypothesis was that early POCUS evaluation prior to resuscitation would be associated with decreased mortality.

MATERIALS AND METHODS

This study was conducted at two academic medical centers. Each hospital has fully staffed EDs and ICUs. The Banner University Medical Center-Tucson campus has an annual ED census of 85,000 and is a Level 1 Trauma center. The Banner University Medical Center-South campus has an annual ED census of 54,000. Emergency medicine (EM) faculty staff both EDs and each medical center supports its own EM residency, although the entire faculty and residents are shared between both EDs. The medical ICUs at each hospital are staffed with residents, pulmonary and critical care fellows, and faculty from the University of Arizona Department of Medicine.

An electronic quality improvement registry is maintained at each facility that includes all patients that are either admitted from the ED to an ICU or die while in the ED. This study was a retrospective cohort study of all adult (≥ 18 yr old) nontrauma patients with hemodynamic instability in the registry at both EDs from November 1, 2013, to October 31, 2016. Hemodynamic instability was defined as a shock index (heart rate/systolic blood pressure) greater than 0.6 (36). Pediatric and trauma patients were excluded. This project adhered to the standards outlined by the Patient-Centered Outcomes Research Institute for the conduct of registry studies (37). This study was reviewed and approved by the University's Institutional Review Board.

POCUS Program

Each ED has dedicated ultrasound systems for bedside use, and the department supports an emergency ultrasound section of faculty and fellows that provide a rigorous ultrasound education to EM residents and faculty. Residents on average graduate with 550 logged POCUS examinations. Ultrasound examinations performed in the ED are archived in the web-based workflow solution, Qpath (Telexy, Maple Ridge, BC, Canada), and undergo a structured quality control process.

Study Procedures

Eligible patients were categorized into one of three groups depending on if and when POCUS was performed in relation to a key therapeutic intervention, which include any fluid bolus, vasopressor bolus, or continuous vasopressor infusion. The timing of POCUS examination was determined from the ED arrival time to the first POCUS performed. If no, POCUS was performed, patients were categorized into cohort 1. When the POCUS was performed within 6 hours but prior to an intervention, the patient was categorized into cohort 2. The remaining patients had POCUS performed after an intervention and were categorized into cohort 3. An a priori subgroup analysis of patients in each cohort with an admission diagnosis of sepsis, severe sepsis, or septic shock was planned.

Outcomes

The primary outcome was death at any point in the hospital stay. Secondary outcomes included proportion of patients that required tracheal intubation, vasopressors, or intubation and the time to each intervention.

Data Analysis

All statistics were performed in Stata 15.1 (StataCorp LLC, College Station, TX). Categorical data were compared using Fisher exact test, and continuous data were compared with the Kruskal-Wallis test. Proportions and 95% CIs were calculated using the Pearson-Clopper exact method for all binary and categorical data, and medians and 95% CIs were calculated using median regression for all continuous variables. A two-sided p value of less than 0.05 was considered significant. For the primary multivariable logistic regression model, a purposeful backward stepwise regression analysis with a threshold for retention in the model of p value of less than 0.20 was constructed for the primary outcome, the primary independent variable (POCUS use) and clinically relevant potential risk factors and confounders. The threshold for inclusion into the multivariable model was a p value of less than 0.2. All variables initially not included in the preliminary model were included one at a time for a final check of statistical significance and confounding (variables that changed the coefficient for the use of POCUS before the first intervention vs no POCUS > 10% were considered significant confounders).

We conducted several sensitivity analyses to account for the potential bias due to the nonrandom assignment of the use of POCUS and the potential bias due to missing data for various risk factors and confounders.

First, we used inverse-probability-weighted regression-adjustment (IPWRA) to estimate the effect of using ultrasound before interventions compared with not using ultrasound to correct for potential bias due to the nonrandom distribution of POCUS use. IPWRA uses the reciprocals of the estimated treatment probability, calculated as a propensity score from a treatment model with the treatment assignment (POCUS before intervention vs no POCUS) as the outcome variable, as weights to estimate the

effect of the treatment on the main outcome, death before hospital discharge, in a logistic regression outcome model (38). We also used propensity score matching, using the propensity scores to match each case (POCUS before—cohort 2) to 1 to 3 controls (no POCUS—cohort 1). We also stratified cohorts 1 and 2 into quintiles based on the propensity scores and conducted our logistic regression analyses separately for each quintile to assess if results were consistent across the range of propensity scores. We formally tested that covariates were balanced for the IPWRA analysis using the overidentification test for covariate balance. For the propensity score analyses, we visually examined the distribution of the propensity scores and covariates.

In addition, we used multiple imputation using chained equations (39) to impute data for variables with missing values to control for bias due to missing data and we repeated all analyses (multivariable logistic regression, IPWRA, propensity score-matched analysis) using the imputed datasets and Rubin's rules (40) to combine estimates and variances across imputed datasets. In our imputation models, we included all variables that could be related to the outcome or treatment (see outcome and treatment model covariates above), using predictive mean matching (oxygen saturation, respiratory rate, lactate level), least squares regression (mean arterial pressure, body temperature, heart rate), and logistic regression (sex, triage acuity), for the chained equations. We created 25 imputed datasets for analysis.

Model diagnostics for influential observations were performed, and model performance was evaluated with the Hosmer-Lemeshow test, calibration belt test (41), link test, and the area under the receiving operator characteristics curve. All continuous independent variables were tested to ensure a linear relationship with the outcome variable in the log-odds (logit) scale and were transformed using fractional polynomials to ensure a linear association with the outcome variable in the logit. To ensure that covariates used to calculate the propensity score were balanced between treatment and control groups, we used the overidentification test for covariate balance (42) and visually inspected the distribution of propensity scores and covariates for both the treatment and control groups to ensure overlapping distributions.

RESULTS

A total of 9,325 adult patients were included in the registry during the study period. Of these, 1,591 trauma patients were excluded. Of the 7,734 study eligible patients, 2,293 patients were excluded for not meeting shock index threshold. The remaining 5,441 patients were included in the analysis: 4,165 in cohort 1 (no POCUS), 614 in cohort 2 (POCUS prior to intervention), and 662 in cohort 3 (POCUS after intervention) (**Fig. 1**). Patient characteristics are listed in **Supplementary Table 1** (Supplemental Digital Content 1, http://links.lww.com/CCX/A48).

Mortality was 22% in cohort 1, 29% in cohort 2, and 26% in cohort 3 ($p < 0.001$) (**Table 1**). In patients with an admission diagnosis of sepsis, severe sepsis, or septic shock, mortality was 29%, 44%, and 27%, respectively ($p = 0.02$). POCUS prior to an intervention was associated with a 37% increase in the odds of death compared to patients with no POCUS performed (adjusted odds ratio [aOR], 1.37; 95% CI, 1.09–1.72) (**Table 2**). POCUS after intervention was not associated with an increased odds of death compared to patients with no POCUS (aOR, 0.98; 95% CI, 0.79–1.24). Dropping overly influential observations had no meaningful changes in model variables.

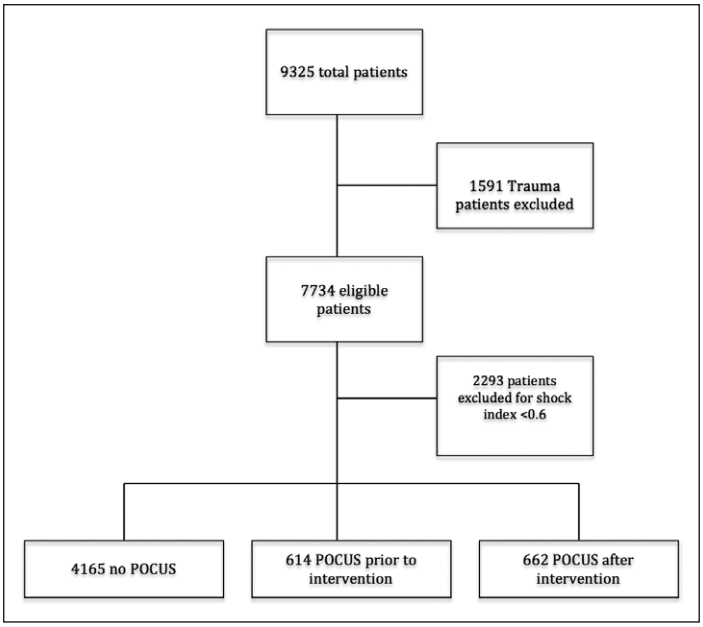

Figure 1. Patient flow chart. POCUS = point-of-care ultrasound.

Sensitivity analyses also showed that cohort 2 had higher mortality compared with cohort 1. **Supplementary Figure 1** (Supplemental Digital Content 2, http://links.lww.com/CCX/A49; **legend**, Supplemental Digital Content 4, http://links.lww.com/CCX/A51) shows a forest plot comparing the odds ratio for death across all primary and secondary analyses as well as the difference in mortality between cohorts 2 and 1. The crude odds ratio for death was the highest (1.43 [1.19–1.73]), whereas the IPWRA analysis using multiple imputation showed the lowest (1.20 [1.001–1.41]). Similarly, the difference (treatment effect) in mortality between cohort 1 and cohort 2 (mortality of cohort 2–mortality of cohort 1) was similarly highest for the crude analysis (mean difference in absolute mortality, 0.068; 95% CI, 0.03–0.11) and lowest for the IPWRA analysis using multiple imputation (difference, 0.032; 95% CI, 0.001–0.066). Odds ratios and absolute mean differences were in between these values for the IPWRA and propensity score-matched analysis (complete case analysis), as well as the adjusted analysis and the propensity score-matched analysis using multiple imputation. Covariates were adequately balanced between the two groups (cohorts 1 and 2) for the IPWRA and propensity-matched analyses based on visual inspection of distributions for each covariate (data not shown), distributions for the propensity scores (**Supplementary Fig. 2**, Supplemental Digital Content 3, http://links.lww.com/CCX/A50; legend, Supplemental Digital Content 4, http://links.lww.com/CCX/A51) and the overidentification test for covariate balance for the IPWRA analysis($p = 0.42$). A sensitivity analysis focused only upon those receiving vasopressors demonstrated that while unadjusted mortality differences remained, adjusted mortality differences are not significant between groups. (**Table 3**).

TABLE 1. Mortality Before Hospital Discharge

Mortality	No POCUS	POCUS Before Intervention	POCUS After Intervention	*p*
Overall	917/4,165	177/614	173/662	
	22.0% (95% CI, 20.8–23.3%)	28.8% (25.3–32.6%)	26.1% (22.8–29.7%)	< 0.001
Patients with sepsis diagnosis	103/353	36/82	38/140	
	29.2% (24.5–34.2%)	43.9% (33.0–55.3%)	27.1% (20.0–35.3%)	0.02

POCUS = point-of-care ultrasound.

Finally, we also stratified cases based on the quintiles of the propensity scores calculated for the above analyses and calculated stratum-specific odds ratios for mortality before hospital discharge for cohort 2 (POCUS before) versus cohort 1 (no POCUS) as well as a pooled estimate. The test for homogeneity ($p = 0.35$) suggests that ORs are homogenous across the five strata (quintiles) of propensity scores. Odds ratios ranged from 2.6 (quintile 1) to 1.2 (quintile 5), with a Mantel-Haenszel pooled estimate of 1.32 (95% CI, 1.07–1.63). We also repeated the adjusted analysis using only individuals with a propensity score greater than 0.1 and less than 0.9. The aOR for death comparing cohort 2 to cohort 1 was 1.29 (95% CI, 1.004–1.658).

Interventions with IV fluids, vasoactive agents, and intubation are listed in **Table 4**. There was a significant difference in time to fluids, with cohort 2 having the longest time to fluid administration.

DISCUSSION

In this study, we explored the impact of POCUS performed in the ED on the outcomes in critically ill patients in our two large academic EDs. We found critically ill patients that had POCUS performed prior to an intervention (cohort 2) had a higher in-hospital mortality. Although a recent prospective clinical trial suggests the ED POCUS has no impact on clinical outcomes (43) in patients with undifferentiated shock patients, ours is the first to suggest an association with potentially adverse outcomes of ED POCUS in critically ill patients.

A key question that needs exploration is: Why POCUS in the ED would result in higher in-hospital mortality? In this cohort study, ED patients that had POCUS prior to intervention had less aggressive treatment interventions in the ED when measured by both the volumes and timing of IV fluid and rates of intubation. These findings suggest POCUS influenced the aggressiveness of the immediate resuscitation in the ED.

Potentially, POCUS results in significant delays in treatment in the ED enough to adversely affect outcomes. Another potential explanation is that there is a group of patients with diagnostic uncertainty that POCUS identified ED patients who otherwise would not have been considered critically ill. Specifically, the etiology of shock upon initial evaluation in the ED is inherently challenging. There are not established characteristics of nontraumatic hypotension and shock in the ED (1). Thus, there may be differences in the role of POCUS in ED patients with undifferentiated shock versus those with obvious etiologies. There also may be differences in the use of POCUS for diagnosis and categorization than for therapy titration. Clearly, POCUS has been proposed not only for diagnostic purposes in shock but also to determine central venous pressure (44) and to guide fluid resuscitation (45).

There may also be a difference in the impact of POCUS between fluids and vasopressors. A sensitivity analysis focused only upon those receiving vasopressors demonstrated that while unadjusted mortality differences remained, adjusted mortality differences are not significant between groups. Yet looking at only patients receiving vasopressors is a limitation. Fluids and vasopressors are the two main interventions available in the ED for a hemodynamically unstable patient. ED POCUS has been widely touted to distinguish the fluid status these patients (hypovolemic, euvolemic, hypervolemic) and whether contractility is compromised. Thus, the purpose of POCUS in the ED is to guide whether to give more fluids, less fluids, or start a vasopressor/inotrope. It is not the ultrasound that changes the outcomes; it is the treatment decisions that come from doing the ultrasound (fluids or vasopressors).

POCUS in critically ill patients has widespread enthusiasm given the potential for rapid, noninvasive, and easily repeatable assessments of hemodynamics. In the ICU setting, there is evidence that POCUS can positively impact care outcomes. In a recent study by Kanji, a hemodynamic-guided echocardiogram was performed in patients admitted to the ICU with undifferentiated shock at a median time of 11 hours from admission. They found an improvement in mortality, which appears due to a reduction in total fluids in day 1 (44). A recent analysis of the Medical Information Mart for Intensive Care-III database showed reduced odds of mortality in patients that received formal echocardiography, interpreted by a cardiologist, in the ICU (45).

Extrapolation of these findings with POCUS in the ICU setting to the ED setting has been acceptable in our institutions given that POCUS allows for earlier diagnosis and treatment, improves confidence in the diagnosis (29–35, 43, 46), and leads to changes in resuscitation strategy 25–30% of the time (35). Indeed, this has led to general recommendations and endorsements for POCUS to be performed in critically ill patients, including in the ED (46, 47). Furthermore, recent literature has shown that a positive fluid balance, generally considered as "over-resuscitation," is associated with a higher mortality in shock (4, 5, 7, 8, 10). An extension of this logic is that patients at risk of fluid overload, such as those with heart failure or renal failure, will be at greater risk of fluid overload. The best estimates of the prevalence of comorbid heart failure and renal failure are 20% and 10%, respectively (8, 9, 11). Additionally, the utility of the fluid bolus has recently come under scrutiny as large database analyses are conflicting over the

TABLE 2. Logistic Regression Analysis for Death Before Hospital Discharge

Outcome = Death Before Hospital Discharge	Univariate Analysis		Multivariable Analysis[a], *n* = 4,509 (Missing = 932)
Covariates	**OR (95% CI)**	***n* (Missing)**	**Adjusted[b] OR (95% CI)**
POCUS use		**5,441 (0)**	
No POCUS (cohort 1)	**Referent**	**–**	**Referent**
POCUS prior to intervention (cohort 2)	**1.43 (1.19–1.73)**	**–**	**1.37 (1.09–1.72)**
POCUS after intervention (cohort 3)	**1.25 (1.04–1.51)**	**–**	**0.98 (0.79–1.24)**
Age (per year)	1.03 (1.02–1.03)	5,441 (0)	1.02 (1.02–1.03)
Log first mean arterial pressure (per log unit)[c]	0.29 (0.23–0.37)	5,265 (176)	0.61 (0.48–0.90)
First measured oxygen saturation (per %)	0.95 (0.95–0.96)	5,334 (107)	0.98 (0.97–0.99)
First measured heart rate < 75 beats/min (vs ≥ 75)	1.49 (1.16–1.92)	5,441 (0)	1.46 (1.05–2.02)
Prehospital intubation (vs no)	4.21 (3.25–5.45)	5,441 (0)	1.48 (1.02–2.14)
Cardiac arrest (vs no cardiac arrest)	26.1 (18.74–36.46)	5,441 (0)	3.24 (2.03–5.16)
Initial lactate (per transformed unit)[c]		4,601 (840)	
Initial lactate^2	1.04 (1.03–1.05)	–	1.02 (1.01–1.03)
Initial lactate^2 × log (initial lactate)	0.99 (0.98–0.99)	–	0.99 (0.99–0.999)
Use of antibiotic (yes vs no)	1.35 (1.18–1.55)	5,441 (0)	1.90 (1.50–2.42)
Vasopressor use (vs no)	5.73 (5.00–6.56)	5,441 (0)	2.97 (2.43–3.63)
No IV fluid administration (vs any fluid)	1.87 (1.61–2.17)	5,441 (0)	1.38 (1.07–1.77)
ICU days (per transformed unit)[c]		5,441 (0)	
Log (ICU days)	1.11 (1.07–1.15)	–	1.58 (1.27–1.96)
(Log [ICU days])^2	1.06 (1.04–1.07)	–	1.07 (1.04–1.09)
Hospital A (vs hospital B)	0.95 (0.83–1.08)	5,441 (0)	1.36 (1.14–1.63)
Male (vs female)	1.05 (0.92–1.20)	5,441 (0)	NS[d]
Heart failure diagnosed (vs not diagnosed)	1.66 (0.95–2.88)	5,441 (0)	NS[d]
Triage level 1 (vs 2 or 3)	3.22 (2.81–3.69)	5,380 (61)	NS[d]
Mode of arrival to emergency department		5,441 (0)	
EMS ground	1.92 (1.63–2.25)	–	NS[d]
EMS air	1.71 (1.15–2.53)	–	NS[d]
Other	2.14 (1.41–3.25)	–	NS[d]
Shock index (per unit of shock index)	2.60 (2.09–3.23)	5,239 (202)	NS[d]
Sepsis alert triggered in electronic medical chart (vs no)	1.34 (1.18–1.52)	5,441 (0)	NS[d]
Sepsis diagnosis (vs no)	1.54 (1.27–1.86)	5,441 (0)	NS[d]
Initial triage body temperature (per °C)	0.86 (0.83–0.90)	5,274 (167)	NS[d]

EMS = Emergency Medical Services, NS = not significant, OR = odds ratio, POCUS = point-of-care ultrasound.

[a]Final model included only complete cases, excluding 932 cases due to missing data. Hosmer-Lemeshow goodness of fit test, $p = 0.32$; area under the curve = 0.779 (95% CI, 0.763–0.795). Link test $p = 0.31$. Calibration belt $p = 0.68$.

[b]Adjusted for all other variables in model.

[c]ORs expressed per unit of the covariate after transformation to meet the assumption of linearity in the logit (log-odds) scale for logistic regression. ORs are shown for comparisons across analyses only because typical interpretation of ORs for transformed variables is difficult.

[d]NS ($p > 0.05$) nor a significant confounder.

The final outcome model (outcome = death prior to hospital discharge) included only cohort assignment (i.e., treatment) and the following variables that were either statistically associated with the outcome ($p \leq 0.05$) or that were judged significant confounders (e.g., inclusion changed the regression coefficients for treatment variable ≥ 10%) as covariates: patient age, triage vitals (mean arterial pressure, O_2 saturation, heart rate), first lactate, any use of vasopressor, IV fluid use, prehospital intubation, patient cardiac arrest during hospital stay, any use of antibiotics, number of ICU days, hospital location; however, the treatment model (outcome = treatment assignment: No POCUS vs POCUS before) included all treatment model covariates and the following additional covariates (all variables in the outcome model plus additional variables) to ensure that as many relevant independent variables potentially associated with the treatment assignment were included: patient sex, triage vitals (first body temperature, respiratory rate, triage acuity), diagnosis of sepsis, hospital, diagnosis of heart failure, sepsis alert in the electronic medical record.

Boldface values indicate main variable of interest. Dashes indicate no applicable number for that field.

TABLE 3. Sensitivity Analysis of Patients Requiring Vasopressors

Unadjusted Mortality			
Death	No POCUS	POCUS Before	POCUS After
Yes, *n* (%)	590/1,271 (46.4)	106/245 (43.3)	133/350 (38)
No, *n* (%)	681/1,271 (53.6)	139/245 (56.7)	217/350 (62)
p		0.018	

Adjusted Mortality[a]	
Death	Adjusted OR (95% CI)
No POCUS	Referent
POCUS before	1.09 (0.80–1.48)
POCUS after	0.87 (0.67–1.14)

OR = odds ratio, POCUS = point-of-care ultrasound.
[a]Adjusted for same variables at outcome model.

contribution of the fluid bolus to the mortality reduction seen with early resuscitation in septic shock (9–11). For these reasons, we hypothesized that POCUS prior to any intervention in the ED should reduce mortality.

Yet, what is less clear is the accuracy of the diagnoses or the impact of the resulting therapeutic interventions. Sekiguchi et al (35) performed focused cardiac ultrasounds on septic patients presenting to their medical ICU. The therapeutic plan was changed in 27%, and confidence in the diagnosis was enhanced in 37%. However, on independent review, providers incorrectly classified left ventricular (LV) function in 40% and right ventricular function in 50%; and no mortality data were reported. In another recent study by Hu et al (48), there is only moderate agreement between physician sonographers in the interpretation of cardiac standstill. In light of our results, this raises the question if physicians are making incorrect decisions based on what they think they see with POCUS? If LV function is impaired, which can be accurately estimated by emergency physicians (49), what is the threshold for using an inotrope in contrast to vasopressors or fluids? A possible explanation for our findings is inaccurate interpretation of POCUS images, and the therapeutic decisions based on those images. Thus, POCUS-related changes in fluid administration and vasoactive agents due to incorrect interpretation could have contributed to the differences in mortality. Perhaps it is not the first POCUS study that matters, but the one that comes after an initial period of resuscitation.

There are several limitations to our study, and these results must be interpreted with caution. We developed our registry to prospectively follow the care and outcomes of all critically ill patients admitted to the ICU from our EDs. Yet there are inherent limitations in these types of registries, including the dependence upon available clinical data rather than standardized research data obtained in an investigator controlled study. We used our formal ED ultrasound program to assure compliance with training and competence of providers performing POCUS and certification of the quality of ultrasound images. Yet, we did not review each individual study for formal cardiac functional measurements. Our methods were designed to reduce bias, however even though our sensitivity analyses retained the significant association with mortality in the POCUS group, the effect sizes were smaller and may be a result of other unmeasured confounders. Our registry also does not include patients that were resuscitated in the ED and avoided ICU admission, which could potentially bias against POCUS. The care the patients received after ICU admission could have been different between the groups as well and could have affected our results.

Furthermore, there are limitations in the analysis of observational studies that require special attention (50) including: 1) Causal inference requires careful consideration of confounding, 2) Interpretation of results should not rely on the magnitude of *p* values, and 3) Results should be presented in a granular and transparent fashion. We do not assert in this report that POCUS is causal. We merely suggest that the impact of POCUS on care processes and outcomes needs to be further interrogated. Our methods were designed to address known confounders and reduce bias, however even though our sensitivity analyses retained the significant association with mortality in the POCUS group, the effect sizes were smaller and may be a result of other unmeasured confounders.

There may be unknown clinical and system confounders in this retrospective cohort analysis. We attempted to control for potential confounders with our IPWRA, which maintained an increase in probability of mortality with POCUS before any intervention. Yet the resulting study data are counter to our original hypothesis that the POCUS-guided resuscitation would improve outcomes. A key known confounder is severity of illness. We used the Emergency Severity Index (ESI) as a measure of severity of illness as the ESI is a good predictor of critical care outcomes (51). ESI has the advantages of reflecting the patient at the time of the initial encounter in the ED (before interventions, including POCUS), being available on all patients (not just a subset) and being uniformly applied across this all-inclusive patient registry of critically ill patients in the ED. With the exception of ESI, all severity of illness scales are calculated by the worst value for each variable in a 24-hour period. When studying an intervention such as POCUS, separating if any difference in severity of illness is a potential confounder or if it is a result of the intervention will be impossible.

Further explorations of the impact on patient outcomes and the optimal role of POCUS in the ED appear warranted despite the widespread adoption of POCUS. Previous technologies that were widely adopted by providers as valuable clinical aids, including MAST trousers, pulmonary arterial catheters, and mixed venous oxygen saturation monitors were eventually found not to impact patient outcomes and even to be harmful (52). Given that a recent randomized controlled trial found no improvement in mortality in undifferentiated shock patients with POCUS use in the ED (52), we propose a larger prospective investigation to

TABLE 4. Key Interventions Received During Resuscitation

Intervention	No POCUS (*n* = 4,165)		POCUS Before Intervention (*n* = 614)		POCUS After Intervention (*n* = 662)	
	n	Percent/Median (95% CI)	*n*	Percent/Median (95% CI)	*n*	Percent/Median (95% CI)
First fluid (%)	4,165	100	614	100	662	100
None	841	20.1 (19.0–21.4)	181	29.4 (25.9–33.3)	23	3.3 (2.2–5.2)
Normal saline	3,185	76.5 (75.2–77.8)	419	68.2 (64.4–71.9)	619	93.5 (91.4–95.2)
Lactated ringers	133	3.2 (2.7–3.8)	14	2.3 (1.3–3.8)	20	3.0 (1.9–4.6)
Hypertonic saline	3	0.1 (0.01–0.2)	0	0 (0–0.6)	0	0 (0–0.6)
Dextrose	3	0.1 (0.01–0.2)	0	0 (0–0.6)	0	0 (0–0.6)
Time to fluids, min (median)	3,324	49 (46–52)	433	94 (87–101)	639	39 (33–45)
Fluid administered, cc per kg (median)	3,324	11.3 (10.1–12.5)	433	11.2 (8.0–14.4)	639	18.5 (15.8–21.3)
Vasopressor (%)	1,271/4,165	30.5 (29.1–31.9)	254/614	39.9 (36.0–43.9)	350/662	52.9 (49.0–56.7)
More than one vasopressor	709/1,271	55.8 (53.0–58.5)	136/245	55.9 (49.0–61.8)	192/350	54.9 (49.5–60.2)
Time to first vasopressor, min (median)	1,271	242 (212–272)	245	311 (243–379)	350	270 (213–327)
First vasopressor (%)	1,271	100	245	100	350	100
Dobutamine	44	3.5 (2.5–4.6)	22	9.0 (5.7–13.3)	9	2.6 (1.2–4.8)
Dopamine	36	2.8 (2.0–3.9)	9	3.7 (1.7–6.9)	10	2.9 (1.4–5.2)
Epinephrine	90	7.1 (5.7–8.6)	6	2.5 (0.9–5.3)	15	4.3 (2.4–7.0)
Epinephrine 1:1,000	10	0.8 (0.4–1.44)	0	0 (0–0.6)	2	0.6 (0.1–2.1)
Epinephrine 1:10,000	240	18.9 (16.8–21.1)	18	7.4 (4.4–11.4)	40	11.4 (8.3–15.2)
Norepinephrine	762	60.0 (57.2–62.7)	166	67.8 (61.5–73.6)	250	71.4 (66.4–76.1)
Phenylephrine	89	7.0 (5.7–8.6)	24	9.8 (6.4–14.2)	24	6.9 (4.4–10.0)
Antibiotics administered (%)	2,506/4,165	60.2 (58.7–61.7)	459/614	74.8 (71.1–78.1)	538/662	81.3 (78.1–84.2)
Intubation location (%)	4,165	100	614	100	662	100
Not intubated	2,687	64.6 (63.2–66.1)	414	67.4 (63.5–71.1)	407	61.9 (58.1–65.7)
Prehospital setting	203	4.8 (4.2–5.5)	20	3.3 (2.0–5.0)	25	3.7 (2.4–5.4)
Emergency department	1,017	24.3 (23–25.6)	131	21.4 (18.2–24.8)	189	28.3 (24.9–31.9)
ICU	258	6.3 (5.5–7.0)	49	8.0 (6.0–10.4)	41	6.1 (4.4–8.2)
Time to intubation, min (median)	1,478	93 (22–385)	200	228 (35–622)	255	163 (29–464)

POCUS = point-of-care ultrasound.

define the optimal role and impact of POCUS in the ED resuscitation of critically ill patients

CONCLUSIONS

POCUS in the ED has been widely adopted by the providers in our academic hospital EDs. Contrary to our hypothesis, POCUS prior to a key intervention in the ED appears to be associated with a higher mortality in critically ill patients with hemodynamic instability. Key questions that need further exploration include how POCUS in the ED may impact resuscitation strategies, treatment times, and patient outcomes through larger prospective studies.

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