Cardiac Dysfunction on Point-of-Care Ultrasound Is Associated With Subsequent Use of Vasoactive Medication in Children With Suspected Systemic Infection

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Objective: To evaluate whether reduced ventricular function identified by cardiac point-of-care ultrasound (POCUS) in children with suspected systemic infection is associated with subsequent use of IV vasoactive medications.

Methods: We conducted a retrospective cohort study of patients aged 1 month to 21 years presenting to a tertiary pediatric emergency department (ED) between 2015 and 2024. Eligible patients underwent cardiac POCUS performed by the clinical team before vasoactive therapy (if any) and received evaluation and treatment for suspected systemic infection. Global ventricular function was categorized as reduced or not reduced based on image review by an expert sonographer. Multivariable logistic regression assessed associations between reduced function and clinical outcomes.

Results: Of 329 included patients, 27 (8.2%) had reduced cardiac function on POCUS, and 55 (16.7%) subsequently received an IV vasoactive. Reduced function was associated with higher odds of IV vasoactive use (aOR = 7.9, 95% CI: 2.7-23.0), ICU admission, and fewer ICU- and hospital-free days. Interrater agreement between bedside and expert interpretation was excellent ($\kappa = 0.90$). Associations remained consistent in secondary analyses using expert interpretations.

Conclusion: Cardiac POCUS findings of reduced ventricular function were strongly associated with subsequent IV vasoactive therapy and worse clinical outcomes. These findings suggest that reduced cardiac function identified on cardiac POCUS is associated with greater illness severity and may support early risk stratification.

Key Words: sepsis, infection, cardiac ultrasound, vasopressors, inotropes

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Sepsis remains a leading cause of morbidity and mortality in the pediatric population.[1] Early recognition and timely intervention, including rapid reversal of shock, are critical components of effective sepsis management.[2] In its early stages, sepsis often presents with nonspecific signs and symptoms, and the clinician must maintain a high index of suspicion, particularly in undifferentiated patients. Identifying children at high risk for clinical deterioration is especially challenging for emergency department physicians, who often must make rapid decisions based on limited initial information. One potential contributor to shock is myocardial dysfunction, often termed sepsis-induced cardiomyopathy. Myocardial dysfunction has been identified as a significant contributor to clinical deterioration and multiorgan dysfunction in children with sepsis and is reported in up to 40% of pediatric septic shock cases.[3,4]

Current sepsis guidelines emphasize early fluid resuscitation to optimize end-organ perfusion.[2] However, in children with impaired myocardial dysfunction, this approach may be detrimental, as these patients may be unable to tolerate rapid, large-volume fluid resuscitation. Consequently, early identification of cardiac dysfunction may help guide resuscitative strategies and vasoactive medication choice and potentially improve outcomes in pediatric septic shock.[5]

Historically, objective assessment of myocardial function in the pediatric emergency department (PED) has been limited by the need for echocardiography by a pediatric cardiologist, which is not always immediately available.[6] Cardiac point-of-care ultrasound (POCUS) has emerged as a valuable bedside tool for assessing global cardiac function in children and is supported by various professional societies.[7–9] Cardiac POCUS performed by pediatric emergency medicine (PEM) physicians allows for rapid, noninvasive evaluation of ventricular function.[10–13] Its use may therefore facilitate the early recognition of myocardial impairment in pediatric patients presenting with suspected infection.[14] Accordingly, recent pediatric sepsis guidelines from the Society of Critical Care Medicine and the European Society of Intensive Care Medicine suggest the use of cardiac and lung POCUS to guide resuscitation in pediatric sepsis and septic shock.[15,16] Prior studies in children admitted to the intensive care unit (ICU) have demonstrated that its use can lead to meaningful changes in clinical management in cases of sepsis and improve alignment with established sepsis management algorithms.[17,18] Despite the growing use of cardiac POCUS and its potential to guide early targeted interventions, its role in

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the early identification of septic shock and need for vasoactive medication in undifferentiated children with suspected systemic infection remains unclear.

The objective of this study was to determine whether global ventricular dysfunction on cardiac POCUS performed in the pediatric emergency department is associated with subsequent vasoactive medication use in children with suspected systemic infection. We hypothesized that reduced cardiac function on POCUS would be associated with vasoactive use.

METHODS

Study Design, Setting, and Population

This retrospective cohort study included patients aged 1 month to 21 years who presented to the PED of a tertiary care center between January 1, 2015, and August 1, 2024. The PED receives ~65,000 visits annually. The study protocol was approved by the hospital's institutional review board. Patients were eligible if they underwent cardiac POCUS during their PED visit and met all of the following inclusion criteria:

1. A qualifying set of vital signs—defined as a systolic blood pressure (BP) with an associated diastolic BP and heart rate (HR) recorded within ±30 minutes of each other—was documented within 6 hours of PED arrival.[19]
2. Evaluation or treatment for suspected infection is defined as meeting any of the following criteria within 6 hours of ED arrival: a temperature below 36 °C or at least 38 °C, administration of a systemic (nontopical) antimicrobial agent, or microbiologic testing (Supplemental Tables S1 and S2, Supplemental Digital Content 1, http://links.lww.com/PEC/B666), excluding routine surveillance cultures.[19]
3. Evaluation and treatment for suspected systemic infection were initiated, defined as the collection of a blood culture and administration of intravenous antibiotics within 24 hours of PED presentation.[19]
4. Cardiac POCUS was performed before the administration of vasoactive medications (if given).
5. The POCUS study had an associated quality assurance (QA) form, completed with an interpretation by the bedside provider and reviewed by a PEM POCUS expert.

Image Acquisition, Interpretation, and Review

POCUS images were acquired by residents, nurse practitioners, physician assistants, PEM fellows, or PEM attendings. To independently perform cardiac POCUS in the study, ED providers had to complete a didactic training session and a minimum of 25 technically adequate cardiac POCUS examinations. To maintain credentialing, providers were required to perform at least 2 cardiac POCUS scans per year. Studies were interpreted in real time by the bedside provider team and recorded in a quality assurance database, QPath (Telexy Healthcare Inc., BC, Canada), which is standard practice at our institution.[10,11] The bedside PED team qualitatively assessed global ventricular function as normal, reduced, severely reduced, indeterminate, or hyperdynamic. Providers could select "indeterminate" if there were limitations in image quality or uncertainty in interpreting the findings on ultrasound. Each study was subsequently reviewed by a PEM POCUS expert, defined as a PEM physician who either completed a fellowship in POCUS or was certified as a Registered Diagnostic Medical Sonographer (RDMS). These experts assessed whether the study was interpretable or technically limited, and whether they agreed with the bedside interpretation.

To be deemed interpretable, image clips from at least 2 of the following 4 cardiac views were required: parasternal long, parasternal short, subxiphoid, or apical 4-chamber. A study was classified as a technically limited study (TLS) by the PEM POCUS expert if either an insufficient number of clips were obtained or key structures were inadequately visualized, preventing interpretation.

Exposures, Covariates, and Outcomes

POCUS interpretations from both the bedside provider team and the PEM POCUS expert were extracted from the QPath database.[10,11] For analysis, patients with reduced or severely reduced function were grouped as "reduced," while those with normal, indeterminate, or hyperdynamic function were grouped as "not reduced."

Patient data were extracted from the electronic health record and included demographics, triage and nursing assessments (eg, capillary refill, mental status), vital signs, volume of intravenous (IV) fluids administered, type and initiation time of vasoactive medications, lactate levels, patient disposition, and mortality.

The primary outcome was the use of vasoactive medications within the first 24 hours after ED arrival, as a treatment-based surrogate for septic shock. Secondary outcomes included 30-day mortality, ICU admission, ICU-free days at hospital day 30, and hospital-free days at hospital day 30. For patients who died within 30 days of ED arrival, ICU-free days and hospital-free days were set to 0.

Analysis

Descriptive statistics were used to summarize demographic and clinical characteristics. Continuous variables were reported as medians with interquartile ranges and compared between groups using the Wilcoxon rank-sum test. Categorical variables were reported as counts and percentages and compared using the χ^2 test. Variables were stratified by cardiac function status (reduced vs. not reduced), determined by the bedside provider. For variables of altered mental status, capillary refill, and lactate, missing values were classified as within normal limits, following the convention of established sepsis screening tools.[20] IV fluid bolus volumes were calculated in mL/kg using documented weight and analyzed only in patients with non-missing weight data.

To identify factors independently associated with IV vasoactive medication use, we performed a multivariable logistic regression. The outcome was receipt of IV vasoactive therapy within 24 hours of ED arrival. Independent variables were selected a priori based on clinical relevance and prior literature: POCUS-assessed cardiac function as determined by the bedside provider (including studies later deemed technically limited by POCUS expert), systolic hypotension [per Pediatric Advanced Life Support (PALS) age-based thresholds, Supplemental Table S3, Supplemental Digital Content 1, http://links.lww.com/PEC/B666], tachycardia (PALS thresholds), altered mental status, capillary refill ≥3 seconds, and elevated lactate (>2.2 mmol/L). Multivariable logistic regressions and

negative binomial regressions were used to assess associations with secondary outcomes.

We also conducted a secondary analysis using PEM POCUS expert interpretations in place of bedside provider interpretations. Studies deemed TLS by the POCUS expert were excluded from this analysis, as they could not be adequately interpreted by the expert.

To assess whether cardiac function on POCUS influenced the choice of vasoactive medication, we recorded the first intravenous vasoactive agent administered during the clinical encounter for each patient who received vasoactive therapy. Medications were categorized by type and stratified based on cardiac function as assessed by POCUS. Counts and percentages were calculated within each cardiac function group, and differences were compared using the Fisher exact test.

We assessed interrater agreement between bedside providers and PEM POCUS experts for the presence of global ventricular systolic dysfunction using Cohen κ statistics. Two κ values were calculated: 1 excluding technically limited studies (since expert interpretation was not possible), and another counting technically limited studies as disagreements to represent lower interpretive agreement.

A two-sided α level of 0.05 was used to determine statistical significance. All analyses were performed using Python version 3.11 (Python Software Foundation) and Stata version 18 (StataCorp).

RESULTS

We identified 329 patient encounters that met our inclusion criteria over the study period (Fig. 1). Table 1 displays demographic and clinical characteristics, stratified by cardiac POCUS outcome. Among our cohort, 27 (8.2%) patients had reduced global ventricular function based on the PEM providers' interpretation. Patients with reduced function were older, with a median age of 12.2 years compared with 8.3 years in the not-reduced group. Those with reduced function received smaller volumes of IV fluid boluses within the first 6 hours. Clinical indicators of poor perfusion—including hypotension, prolonged capillary refill, and elevated lactate—were more common in the group with reduced function identified by POCUS.

In the adjusted analysis, reduced cardiac function on POCUS was strongly associated with the need for IV vasoactive medications, with an odds ratio of 7.9 (95% CI: 2.7-23.0; Fig. 2). Other factors independently associated with vasoactive use included systolic hypotension and elevated lactate. In contrast, tachycardia, altered mental status, and prolonged capillary refill were not significantly associated with vasoactive administration in the multivariable model. In the secondary analysis, which used POCUS expert interpretation instead of bedside interpretation and excluded TLS cases (n = 322), the multivariable regression results remained largely consistent with the primary analysis (Fig. 3). Seven POCUS exams were deemed to be TLS by the PEM POCUS expert. Reduced cardiac function on POCUS remained significantly associated with increased odds of vasoactive medication administration (OR = 8.0, 95% CI: 2.77-23.26).

Interrater agreement between bedside provider interpretation and POCUS expert interpretation was excellent. When TLS cases were excluded, overall agreement was 96.6% with a κ of 0.903 (95% CI: 0.83-0.98), indicating excellent agreement. When TLS cases were counted as disagreement to assess a more conservative estimate, agreement remained high at 94.5% with a κ of 0.853 (95% CI: 0.78-0.93).

In adjusted analyses of secondary outcomes, reduced cardiac function on POCUS was associated with increased likelihood of ICU admission ($P < 0.01$), and fewer ICU-free days ($P < 0.01$) and hospital-free days within the 30-day

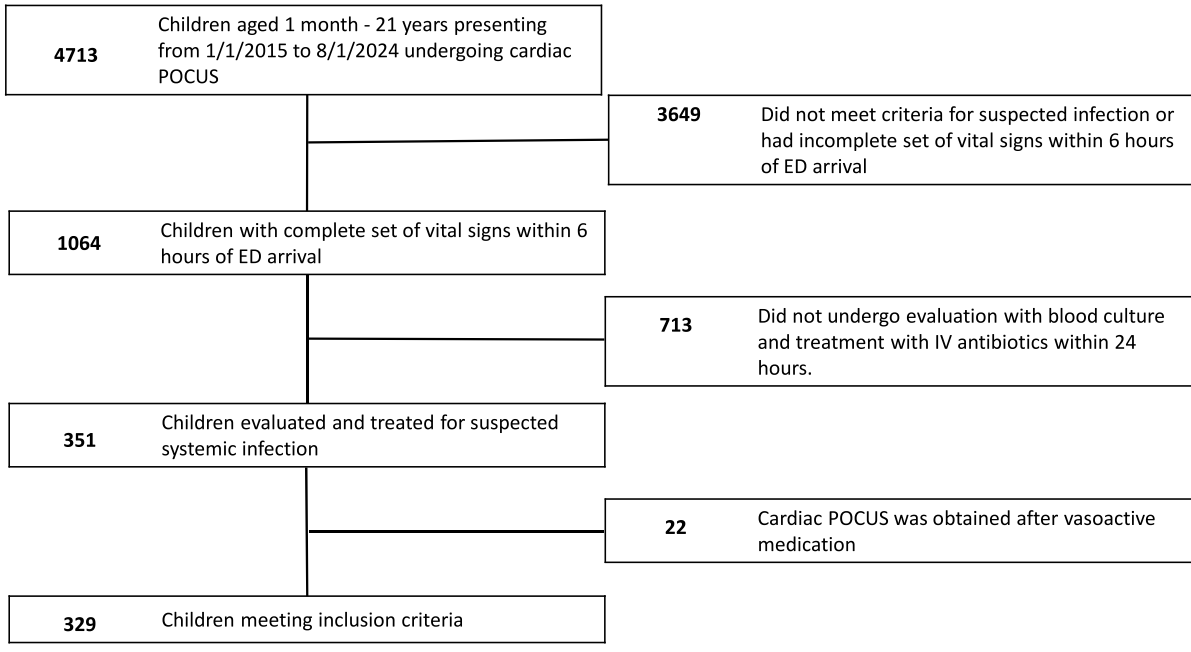

FIGURE 1. Flow diagram.

TABLE 1. Patient Characteristics

	Overall (n = 329)	Not-Reduced Function (n = 302)	Reduced Function (n = 27)
Age (yr), median [IQR]	8.6 [4.4-15.0]	8.3 [4.3-14.8]	12.2 [6.5-17.8]
Female sex	141 (42.9)	128 (42.4)	13 (48.2)
Time from ED arrival to POCUS (hr), median [IQR]	2.8 (1.5-4.6)	3.0 [1.6-4.8]*	1.61 [0.4-2.3]
IV fluid given as bolus in first 6 h (mL/kg), median [IQR]†	20 [9.4-40.3]	20.0 [9.9-40.3]	10.2 [0-20.1]*
Hypotension (by PALS)	79 (24.0)	65 (21.5)	14 (51.9)*
Tachycardia (by PALS)	275 (83.6)	253 (83.8)	22 (81.5)
Altered mental status‡	107 (32.5)	95 (31.5)	12 (44.4)
Capillary refill time ≥ 3 s‡	136 (41.3)	119 (39.4)	17 (63.0)*
Lactic acid > 2.2 mmol/L‡	75 (22.8)	63 (20.9)	12 (44.4)*
IV vasoactive administered	55 (16.7)	39 (12.9)	16 (59.3)*
Time from ED arrival to IV vasoactive administered (hr), median [IQR]	4.0 [2.4- 6.3]	4.6 [2.5-6.8]	3.1 [1.7-4.6]
Time from POCUS to IV vasoactive administered (hr), median [IQR]	1.6 [0.5-4.1]	1.6 [0.3-4.9]	1.4 [0.7-2.0]
Death within 30 d	8 (2.4)	7 (2.3)	1 (3.7)
ICU admission	153 (46.5)	130 (43.1)	23 (85.2)*
ICU-free days at 30 d, median [IQR]	30 [26.6-30]	30 [26.9-30.0]	26.8 [14.3-28.6]
Hospital-free days at 30 d, median [IQR]	25.1 [17.1-27.9]	25.7 [18.9-28.0]	14.6 [0-24.9]*

Values are presented as n (%) unless specified.
*$P < 0.05$ by χ^2 test (for dichotomous variable) or Wilcoxon rank-sum test (for continuous variables).
†N = 319 due to missing weight values for 10 encounters.
‡Missing values were classified as normal.

follow-up period ($P < 0.05$; Table 2). There was no significant association between reduced function and 30-day mortality. Among patients who received vasoactive medications, epinephrine was the most commonly used in both reduced (37.5%) and nonreduced (38.5%) function groups (Table 3). Norepinephrine was not used in the reduced function group (0% vs. 33.3%), while dopamine was more frequent in the reduced function group (43.8% vs. 25.6%). Milrinone was exclusively administered to patients with reduced function (18.8% vs. 0%), and no significant differences were observed for vasopressin.

DISCUSSION

Cardiac POCUS represents a potential tool for early identification of myocardial dysfunction among pediatric patients presenting to the ED with suspected systemic infection. This study aimed to evaluate the association between reduced ventricular function on cardiac POCUS and the subsequent use of intravenous vasoactive medications in pediatric patients presenting to the ED with suspected infection. We found that global ventricular dysfunction, as interpreted by both bedside providers and POCUS experts, was significantly associated with increased

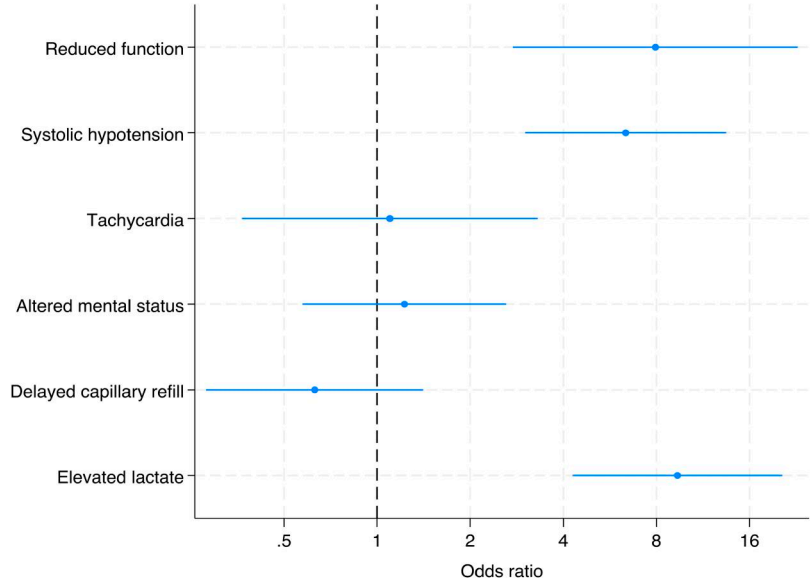

FIGURE 2. Multivariate odds ratios for variables associated with initiation of intravenous vasoactive medication within 24 hours of arrival. Reduced function on POCUS is established based on the bedside provider's interpretation.

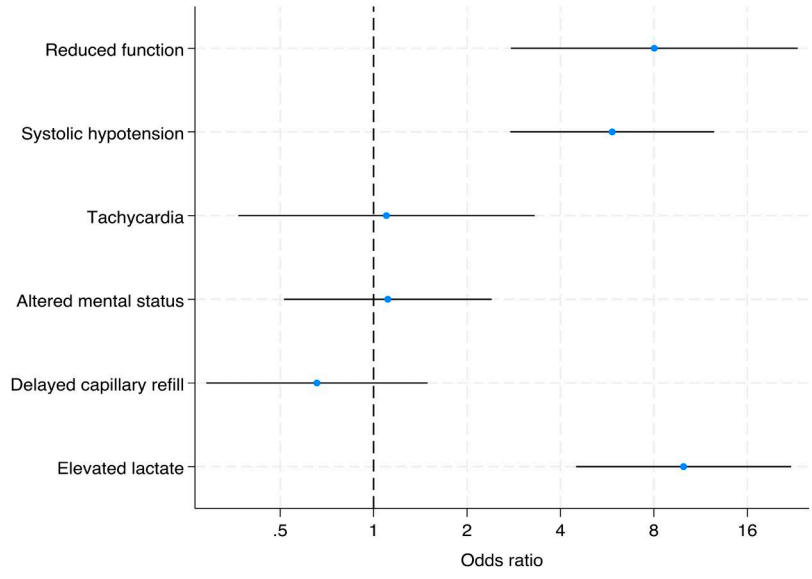

FIGURE 3. Multivariate odds ratios for variables associated with initiation of intravenous vasoactive medication within 24 hours of arrival, using PEM POCUS expert interpretations of cardiac function. Studies deemed technically limited (TLS) by the expert were excluded (n = 322).

odds of vasoactive medication administration. Our findings suggest that cardiac POCUS may have utility in risk stratification during the evaluation of undifferentiated children with suspected systemic infection.

Early sepsis care presents significant challenges for emergency medicine physicians. In children, the relatively low prevalence of sepsis requires a high index of suspicion for timely recognition.[21,22] Even when sepsis is identified, ongoing reassessment is complicated by the limited reliability of physical examination findings. Prior research has demonstrated that traditional clinical indicators used to assess shock, such as capillary refill, pulse pressure, and extremity temperature, show poor interrater agreement and limited predictive value in pediatric populations.[23] Furthermore, selecting vasoactive agents based on shock type, as determined by these clinical signs, has not been shown to improve outcomes.[24] These limitations highlight the difficulty clinicians face when relying solely on traditional clinical markers to guide resuscitative strategies in pediatric septic shock. In our study, potentially late indicators of poor perfusion, such as systolic hypotension and elevated lactate, were independently associated with the need for vasoactive support. However, other commonly used clinical signs, including tachycardia, altered mental status, and prolonged capillary refill, were inconsistently associated with vasoactive use. These findings reinforce the need for more physiologically informed and reliable tools for early risk stratification.

Our findings support the potential role of cardiac POCUS in assessing pediatric patients with suspected systemic infection to identify those at increased risk for developing shock. We used bedside provider interpretation as the primary exposure to reflect real-world clinical practice, recognizing that emergency physicians often lack immediate access to PEM POCUS experts or cardiology-performed echocardiography, particularly in time-sensitive situations such as sepsis. The interrater agreement between bedside and expert POCUS interpretations was excellent, as described in prior studies.[10–13] Based on these results, bedside providers should feel empowered to rely on their cardiac POCUS during the evaluation of children with suspected infection after completing adequate credentialing. In addition, we focused on children with suspected systemic infection rather than confirmed sepsis to reflect the diagnostic uncertainty typical of ED presentations, including early sepsis. In our cohort, hypotension was present in

TABLE 2. Adjusted Odds Ratios and β Coefficients of Reduced Ventricular Function on POCUS for Secondary Outcomes (n = 329)

	Death Within 30 d*	ICU Admission*	ICU-Free Days†	Hospital-Free Days†
Reduced cardiac function	1.21 (0.13-11.58)	5.30 (1.57-17.95)‡	−0.225 (−0.391 to −0.059)‡	−0.294 (−0.576 to −0.012)§
Systolic hypotension	0.77 (0.13-4.50)	2.72 (1.42-5.20)‡	−0.107 (−0.213 to −0.001)§	−0.153 (−0.334 to 0.027)
Tachycardia	0.49 (0.09-2.59)	1.61 (0.75-3.46)	−0.020 (−0.138 to 0.097)	−0.044 (−0.245 to 0.158)
Altered mental status	1.05 (0.23-4.89)	6.04 (3.38-10.79)‡	−0.184 (−0.281 to −0.086)‡	−0.295 (−0.461 to −0.130)‡
Capillary refill ≥ 3 s	0.96 (0.19-4.71)	1.90 (1.10-3.31)§	−0.015 (−0.112 to 0.081)	−0.033 (−0.199 to 0.132)
Lactate ≥ 2.2 mmol/L	3.93 (0.81-19.13)	3.09 (1.57-6.06)‡	−0.123 (−0.235 to −0.012)§	−0.202 (−0.393 to −0.012)‡

*Odds ratio based on logistic regression used for death and ICU admission.
†Expected rate ratio based on negative binomial regression used for ICU-free and hospital-free days.
‡$P < 0.01$.
§$P < 0.05$.

TABLE 3. First IV Vasoactive Infusion Administered

Vasoactive Medication, n (%)	Total	Nonreduced Function	Reduced Function
Epinephrine	21 (38.2)	15 (38.5)	6 (37.5)
Norepinephrine	13 (23.6)	13 (33.3)	0*
Dopamine	17 (30.9)	10 (25.5)	7 (43.8)*
Vasopressin	1 (1.8)	1 (2.6)	0
Milrinone	3 (5.5)	0	3 (18.8)*
All vasoactive medications	55	39	16

*$P < 0.05$ by the Fisher exact test.

52% of patients with reduced cardiac function, suggesting that cardiac POCUS may help identify deteriorating patients earlier, even before overt shock develops. Many patients may not meet full sepsis criteria until hours into their clinical course; therefore, cardiac POCUS may be especially valuable during this early window when decisions about fluid resuscitation and escalation of care must be made with limited diagnostic clarity.

Our data suggests that POCUS findings may be associated with changes in clinical management. PEM providers administered smaller fluid volumes to patients with reduced cardiac function, and none of the patients with reduced function were initially treated with norepinephrine. This pattern may reflect clinicians' efforts to avoid fluid overload and increased afterload, caused by norepinephrine's vasoconstrictive effects, in patients with suspected myocardial dysfunction, demonstrating an intuitive integration of functional cardiac assessment into bedside decision-making. These findings underscore the importance of further research in this area. Future studies should investigate the optimal timing of cardiac POCUS during sepsis care, whether aligning vasoactive therapy with POCUS findings improves clinical outcomes, and whether integrating cardiac POCUS into pediatric sepsis care bundles enhances overall management and patient outcomes. In addition, evaluating the potential role of repeat cardiac POCUS studies to monitor function over time may provide further insight into dynamic clinical decision-making. Given the low prevalence of reduced function and relevant outcomes, multicenter prospective studies are warranted to validate and extend our findings.

This study has several limitations. It was conducted at a single academic center using a retrospective design, which limits generalizability. Due to its retrospective nature, certain clinical variables (eg, altered mental status and lactate level) had incomplete data, which may have led to under- or overestimation of their associations with clinical outcomes. Due to the retrospective nature of the study, we could not determine whether the decision to initiate vasoactive therapy preceded cardiac POCUS acquisition; however, all included patients underwent POCUS before vasoactive administration, with a median interval of 1.6 hours. Therefore, this study demonstrates an association between reduced cardiac function and clinically relevant outcomes, rather than a direct impact of POCUS on bedside clinical decision-making. This study is subject to selection bias as the decision to perform cardiac POCUS was made at the discretion of the bedside provider. This likely resulted in a cohort with patients in whom myocardial dysfunction was suspected, potentially overestimating the prevalence and clinical impact of reduced cardiac function on POCUS and thereby influencing providers' decisions to initiate vasoactive therapy. In addition, while our broad inclusion criteria may have included some viral illnesses without hemodynamic compromise, these patients may still have been more acutely ill than a broader population of children with suspected systemic infection, as reflected by the high hospital and ICU admission rates in our cohort. The presence of preexisting myocardial dysfunction was not systematically assessed, and baseline cardiac function data were generally unavailable. This limits the ability to determine whether reduced cardiac function observed on POCUS was truly acute and related to the current illness, or represented a chronic condition, potentially confounding the observed associations with clinical outcomes. Although the study draws from nearly a decade of data, outcomes such as reduced cardiac function and vasoactive use were relatively rare, resulting in wide confidence intervals that limit the precision of effect estimates. Finally, while multivariable modeling adjusted for key confounders, unmeasured variables may still have influenced the observed associations.

CONCLUSIONS

Reduced cardiac function identified by POCUS was associated with increased use of vasoactive medications and worse clinical outcomes in pediatric patients with suspected systemic infection. These findings highlight the potential role of cardiac POCUS in identifying children at risk for hemodynamic compromise. Multicenter prospective studies are warranted to validate these associations and to further define the utility of cardiac POCUS in the care of children at risk for sepsis.

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