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Original Research Article

Point-of-care ultrasound-guided hemodynamic assessment and resuscitation in neonatal shock: a prospective observational study

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ABSTRACT

Background: Neonatal shock is a major contributor to morbidity and mortality in neonatal intensive care units (NICUs). Clinical assessment alone often fails to accurately identify the underlying hemodynamic disturbance, which can delay appropriate management. Point-of-care ultrasound (POCUS) has emerged as a rapid bedside tool for evaluating cardiovascular status in critically ill neonates. This study aimed to assess the utility of POCUS in identifying the etiology of neonatal shock and its influence on therapeutic decision-making.

Methods: This prospective observational study was conducted in the NICU of the Department of Pediatrics and Neonatology in collaboration with the Department of Cardiology at Sher-i-Kashmir Institute of Medical Sciences (SKIMS), Srinagar, over an 18-month period. Neonates presenting with clinical features of shock were enrolled. Infants with congenital heart disease, cardiomyopathy, or structural valvular abnormalities were excluded. Bedside POCUS with focused echocardiography was performed at admission and during follow-up. Hemodynamic parameters including inferior vena cava (IVC) diameter, IVC collapsibility index (IVC-CI), and IVC/aorta ratio (AO) ratio were assessed. The relationship between ultrasound findings, etiology of shock, and subsequent management decisions was analyzed.

Results: A total of 110 neonates with shock were included. Septic shock was the most common etiology (41.6%), followed by cardiogenic shock (34.5%) and hypovolemic shock (23.6%). Early-onset shock (≤24 hours of life) was observed in 72.7% of cases. Significant variations in IVC parameters were observed among the different types of shock ($p<0.05$). Neonates with hypovolemic shock demonstrated higher IVC collapsibility, while cardiogenic shock was associated with increased IVC diameter and reduced collapsibility. POCUS findings resulted in modification of clinical management in a substantial proportion of cases, including optimization of fluid resuscitation, initiation or adjustment of inotropic therapy, and targeted supportive care. The overall mortality rate was 9.1%.

Conclusions: POCUS provides rapid, bedside hemodynamic assessment in neonates with shock and aids in differentiating underlying etiologies. Its integration into routine NICU practice can facilitate timely, targeted management and may improve clinical outcomes.

Keywords: Neonatal shock, Point-of-care ultrasound, Focused echocardiography, Hemodynamic monitoring, NICU

INTRODUCTION

Shock is a pathophysiologic state characterised by an imbalance between oxygen supply and oxygen demand in the tissues leading to tissue hypoxia.[1] Myocardial dysfunction, abnormal peripheral vasoregulation and hypovolemia leading to decreased delivery of oxygen and nutrients to tissues are often the primary sources of neonatal shock. In the first phase of shock, perfusion and oxygen delivery is maintained towards the so-called vital organs (heart, brain, and adrenal glands) by selective regional vasodilation in combination with vasoconstriction to non-essential tissues, such as muscles, skin, kidneys and the splanchnic tissues.[2] This compensated stage of shock is the result of neuroendocrine mechanisms. As the product of cardiac output (which falls) and systemic vascular resistance (which increases), blood pressure actually remains in the normal range in a compensated shock. When this redistribution fails, perfusion and oxygenation of the vital organs will become impaired, resulting in multi-organ dysfunction.[3] It is in this phase of uncompensated shock that systemic hypotension might be expected. It should however be noted that-although controversial-data suggest that in very preterm infants the forebrain might be considered a non-vital organ, since the vasculature supplying the forebrain constrict in response to a decrease in perfusion.

Pathophysiology of shock in newborns is unique since it is associated with physiologic transition from fetal circulation to neonatal circulation at birth. Suprasystemic pulmonary vascular resistance (PVR) in the prenatal period may remain elevated, especially in the presence of ongoing hypoxia and acidosis from sepsis, leading to persistent pulmonary hypertension of the newborn (PPHN). The latter contributes to right ventricular failure, and as such may need therapies directed to decrease right sided pressures. In addition to PPHN, newborn shock may be associated with closure of ductus arteriosus in a ductal dependent congenital heart lesion, as such requiring prostaglandin infusion to open and maintain patency of the ductus arteriosus (PDA). The key to the management of shock in neonates is early recognition and identifying the underlying pathophysiology. The earlier clinical findings include pallor, poor feeding, tachycardia, tachypnea temperature and stability. Sudden unexpected clinical deterioration or cardiorespiratory instability is common in neonates and is often referred as a "crashing" neonate. The established resuscitation guidelines provide an excellent framework to stabilize and evaluate these infants, but it is primarily based upon clinical assessment only. However, clinical assessment in sick neonates is limited in identifying underlying pathophysiology thence, specific designed protocols have been designed for neonatal emergencies for shock that include; The Crashing Neonate Protocol (CNP), utilizing POCUS. It can be applied both in term and pre-term neonates in the NICU. These proposed protocols involve a stepwise systematic assessment with basic ultrasound views which can be easily learnt and reproduced with focused structured training on the use of portable ultrasonography (similar to the FAST and BLUE protocols in adult clinical practice).[4] A specific international working group of experts in POCUS was created to develop a screening protocol incorporating a quick bedside multiorgan ultrasound evaluation to understand the underlying mechanism of deterioration in a critically unwell newborn. POCUS is an imaging modality that continues to gain acceptance in pediatric and neonatal medicine. While ultrasound initially served as a clinical tool with a consultative model with radiology and cardiology disciplines, the value of POCUS in assessment of the heart and other organs is slowly being recognized. In neonatology throughout many areas of the world, functional echocardiography performed by neonatologists has been at the forefront in the growth of POCUS compared to non-cardiac POCUS.[5,6]

Since the introduction of POCUS into clinical medicine more than two decades ago and its fairly widespread use in many parts of the world, its use in pediatric emergency medicine, pediatric critical care, and neonatal perinatal medicine is currently rapidly expanding.[7-10] Although POCUS has been undoubtedly the most recent addition to the modern physician's medical bag and has simultaneously been incorporated into medical school curriculum, unfortunately, there are not yet any published guidelines regarding the implementation of POCUS programs in NICUs in the United States. Canada, Australia, and New Zealand have formal accredited training and certification programs for POCUS for neonatology trainees as well as for many other subspecialties.[11] Recently, the first international evidence-based POCUS guidelines for the use in neonatology and pediatric critical care were published.[12] These guidelines recommended the use of POCUS by clinicians for specific indications in procedural and diagnostic applications but did not provide a comprehensive assessment of specific clinical applications amenable to ultrasonographic interrogation.

Although the performance and interpretation of ultrasonography (US) have traditionally been limited to pediatric radiologists and pediatric cardiologists, POCUS refers to ultrasonography performed at the bedside by non-radiology and non-cardiology practitioners to assist procedures and perform a time-sensitive assessment of the symptomatic patient with immediate identification of pathologic processes that can guide resuscitative and lifesaving interventions.[13-15]

Recently, three expert-consensus statements have been published recommending its use in the NICU and various terminologies have been used to describe the use of echocardiography by the neonatologists-targeted neonatal echo cardiography (TNE), POCUS, neonatologist performed echocardiography (NPE), and clinician performed ultrasound (CPU). All the expert consensus statements have emphasized on establishing a structured training program and accreditation process for the neonatologists.[12-14]

Echocardiography can be used for structural assessment (performed to diagnose or rule out congenital heart defect) or functional assessment (focused evaluation of hemodynamics or cardiac function). Functional echocardiography can be used to address a specific clinical question or acquire additional physiological information helping the clinician in making decision bedside or in providing targeted therapy.[11]

Echocardiography can play an important role in managing infants with neonatal shock. American College of Critical Care Medicine (ACCM) clinical guidelines and practice parameters have suggested using bedside echocardiography in hemodynamic evaluation and its management in patients with neonatal shock. Infants with moderate to severe hypoxic-ischemic encephalopathy (HIE) often have ventricular dysfunction, systemic hypotension and pulmonary hypertension. Functional echocardiography may be used to guide the appropriate intervention to normalize hemodynamics and optimize tissue perfusion.

Ultrasound-guided central line placement is a standard practice in adults and children. Point-of-care echocardiography is increasing being used for central line placement and checking the position of umbilical catheters in neonates. Imaging IVC-right a trial junction and descending aorta in subcostal view can easily facilitate checking the position of umbilical venous and arterial catheters, respectively. Few studies have suggested echocardiography may be more reliable than X-rays to confirm umbilical catheters position.[16,17] While confirming the position on X-ray is considered as gold standard, role of echocardiography is evolving and may have an important role in future.

The role of echocardiography in the NICU has rapidly evolved over the last two decades and there are now guidelines to direct Neonatologist Performed Echocardiography (NPE). Expert consensus statements have provided a framework for echocardiography training, scope of practice, and clinical governance structure for neonatologists. Now NPE is routinely being used a standard of care in the NICUs across the world. It is referred to as NPE, targeted neonatal echocardiography, point of care echocardiography or functional echocardiography, depending upon the country's guidelines. The terms are used somewhat interchangeably, but functional echocardiography is aimed less at the identification of structural abnormalities and more at determining cardiac function. Clinical examination and the existing tools for the haemodynamic monitoring in the neonatal intensive care lack sensitivity and specificity, and they are indirect parameters of cardiovascular well-being. Functional echocardiography provides direct assessment of haemodynamics at bedside. It is now widely regarded as a useful extension to the clinical examination and other monitoring tools in the critically ill infant. This review article provides an overview of the five most common applications of NPE in the NICU; diagnosis and haemodynamic evaluation of PDA, diagnosis and evaluation of pulmonary hypertension, diagnosis of pericardial effusion and guide pericardiocentesis, assessment of cardiac functions and fluid volume status (pre-load). It describes how NPE can be used by the healthcare professionals to optimize care for sick neonates with haemodynamic instability.[18]

The present study was aimed to describe the indications for echocardiography, the yield of positive findings, and the resulting changes in clinical management when echocardiography is performed on the neonatal unit.

METHODS

The present was a prospective observational study, conducted in Department of Pediatrics and Neonatology and Cardiology SKIMS, Srinagar. The study was done over a period one and a half year after obtaining ethical clearance from institutional ethical committee. Informed consent in local language from the patients before their inclusion in the study was conducted properly.

Inclusion criteria

Patients with strong clinical suspicion of septic shock at the time of admission to the NICU were included. Septic shock was diagnosed according to the ACCM clinical practice parameters for hemodynamic support of pediatric and neonatal septic shock 2017 by clinical signs, including hypothermia or hyperthermia, altered mental status, and peripheral vasodilation (warm shock) or vasoconstriction with capillary refill time (CRT) greater than 2 seconds (cold shock) before hypotension occurs.

Exclusion criteria

All cases included were considered to be in a state of fluid refractory septic shock when they received at least 40 ml/kg shock fluids (normal saline or Ringer's lactate) and required inotropic/ vasopressor support for hemodynamic resuscitation, whether ventilated or not. Patients with congenital heart diseases, cardiomyopathy, and valvular disorders were excluded.

After informed consent was obtained from the caregiver, transthoracic two-dimensional, M-mode, and Doppler echocardiography was performed on commercially available echocardiographic equipment (GE, Logic P3) using a 6S probe. Echocardiography was performed to measure the LVOT diameter measured in the long-axis parasternal view, and the time-velocity integral of the flow wave across the aortic valve (VTI) was obtained by pulsed wave Doppler. All ultrasound images obtained by the NICU physician and sonographer were stored and then verified by pediatric cardiologist using a scale to rate the acceptability of the ultrasound measurements. Left ventricular outflow tract-velocity time integral is a Doppler-derived measure of the distance traveled by midstream blood through the left ventricular outflow tract in a single cardiac cycle, i.e., stroke distance. Left ventricular outflow tract diameter was obtained by measuring the distance from inner edge to inner edge, where the right aortic valve coronary cusp meets the interventricular septum to where the noncoronary cusp meets the anterior mitral valve leaflet, in a line parallel.

All cases were subjected to full clinical and echocardiographic examination at the time of NICU admission before inotropic support (Time 0), after 6 hours, after 24 hours and then at the time of stabilization (resuscitation point), which was identified by normalization of heart rate (resolved tachycardia), blood pressure (resolved hypotension if present), CRT (less than 2 seconds), good urine output (≥1 mL/kg per hour), and regaining of consciousness with the start of vasoactive drug withdrawal. Different vasoactive agents were used in management of the study cases with fluid refractory septic shock. These agents included adrenaline, noradrenaline, dobutamine, milrinone, and dopamine.

IVC min (Minimum IVC diameter)

This is the smallest diameter of the IVC during the respiratory cycle. In spontaneously breathing patients, it’s typically measured during inspiration when IVC collapses due to negative intrathoracic pressure pulling blood into chest.

What it indicates: Lower IVC min suggests low intravascular volume or hypovolemia. Higher IVC min can suggest elevated right atrial pressure, volume overload, or poor collapsibility (as seen in cardiac tamponade or cardiogenic shock).

IVC max (Maximum IVC diameter)

This is the largest diameter of the IVC during the respiratory cycle.

In spontaneously breathing patients, typically measured during expiration when the IVC is most distended.

What it indicates: Larger IVC max might indicate volume overload or elevated right atrial pressure. Smaller IVC max may be seen in hypovolemia.

IVC-CI%

Calculated using the formula: IVC-CI%=(IVC max)-{IVC min}/(IVC max).

It represents the percentage collapse of the IVC during inspiration.

What it indicates: Higher IVC-CI% (usually >50%) suggests a lower central venous pressure (CVP) and potential hypovolemia (good collapsibility=low filling pressures). Lower IVC-CI% (usually <20-30%) indicates poor collapsibility, which can be seen in volume overload, elevated CVP, cardiogenic shock, or tamponade.

AO (Aorta diameter)

Diameter of the abdominal aorta, usually measured just above the IVC-AO confluence. Acts as a size reference because it’s relatively unaffected by volume status. Mostly constant in size; used to normalize IVC measurements. Large aorta with small IVC suggests hypovolemia.

IVC min/AO (%)

Ratio of minimum IVC diameter during inspiration to aortic diameter. Lower ratio (<40-50%) suggests hypovolemia (small IVC relative to AO). Higher ratio (>60%) suggests elevated right atrial pressure or volume overload (e.g., cardiogenic shock).

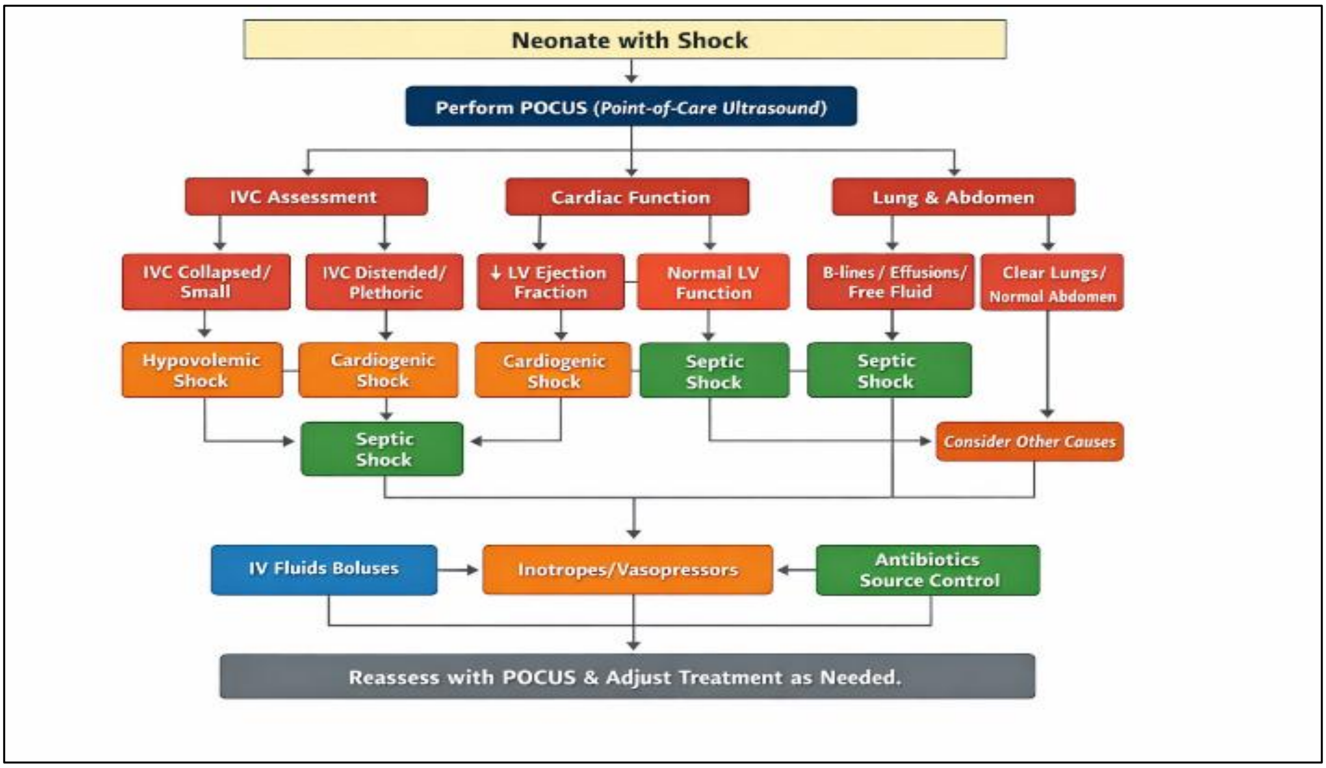

Figure 1: Diagnostic and management framework.

IVC max/AO (%)

Ratio of maximum IVC diameter during expiration to aortic diameter. Higher ratio indicates volume overload or poor venous return (cardiac dysfunction). Lower ratio may reflect hypovolemia or high collapsibility.

A structured POCUS approach was used for hemodynamic assessment in all neonates. The algorithm incorporated evaluation of IVC dynamics, cardiac function, and lung and abdominal findings to identify the underlying etiology of shock. The diagnostic and management framework is illustrated in Figure 1.

RESULTS

Study population and demographics

A total of 110 neonates with clinical shock were enrolled in the study. Cohort consisted of 63 males (57.3%) and 47 females (42.7%). Mean gestational age 34.58±4.14 weeks, with 64.5% (n=71) being appropriate for gestational age (AGA) and 35.5% (n=39) small for gestational age (SGA). Most neonates were of normal birth weight (64.5%), while 24.5% were low birth weight and 10.9% were very low birth weight. Delivery was primarily via LSCS (77.3%) compared to the NVD (22.7%).

Table 1: Baseline characteristics of the study population.

Characteristic	Value
Total no. of patients	110
Male sex	63 (57.3)
Female sex	47 (42.7)
Gestational age (in weeks)	34.6±4.1
Birth weight (kg)	2.3±0.4
SGA	39 (35.5)
AGA	71 (64.5)

Table 2: Clinical and laboratory characteristics.

Variables	Mean±SD
Heart rate (beats/min)	178.7±26.8
Systolic blood pressure (mmHg)	57.2±8.5
Diastolic blood pressure (mmHg)	24.3±4.9
pH	7.2±0.1
Lactate (mmol/l)	4.2±1.2

Clinical presentation

Septic shock was the most frequent clinical diagnosis (41.6%), followed by cardiogenic shock (34.5%) and hypovolemic shock (23.6%). The most common clinical symptoms included fever (40%), hypothermia (14.5%), and lethargy (14.5%). Hemodynamic and laboratory markers at admission showed mean heart rate of 178.65±26.77 bpm, mean SBP of 57.24±8.46 mmHg, and a mean serum lactate of 4.2±1.2 mmol/l.

Etiology of shock

Septic shock was the most common etiology, accounting for 41.6% of cases, followed by cardiogenic shock (34.5%) and hypovolemic shock (23.6%).

POCUS findings

Cardiac Function: The mean left ventricular ejection fraction across all patients was 46.20±11.93%. Most neonates (44.5%) had an ejection fraction between 55% and 60%, and none had values below 30%.

POCUS and vascular assessment

IVC-CI

Neonates with hypovolemic shock exhibited a significantly higher IVC-CI (46±6.14%) compared to those with septic (30.36±5.98%) or cardiogenic shock (31.20±6.4%) ($p<0.001$).

IVC/AO

IVC min/AO ratio was significantly lower in hypovolemic group (46±8.0%) compared to septic (54.7±8.0%) and cardiogenic (55.0±8.2%) groups ($p=0.012$).

IVC dimensions

Cardiogenic shock was characterized by significantly higher mean IVC min (3.2±0.5 mm) and IVC max (3.7±0.6 mm) values compared to other shock types ($p<0.001$).

Impact on clinical management

POCUS findings led to significant modifications in treatment plans (p<0.001):

Fluid resuscitation

Following POCUS, fluid administration was increased to 100% in both hypovolemic and septic shock groups. Conversely, in the cardiogenic shock group, fluid administration was reduced from the 100% to 42.1% (n=16).

Inotropic support

There were significant shifts in vasopressor use; noradrenaline administration increased in septic shock (39.1% to 78.3%, p<0.001) but decreased in cardiogenic and hypovolemic shock. In contrast, adrenaline use increased significantly in cardiogenic shock (55.3% to 100%) and hypovolemic shock (30.8 percent to the 76.9 percent).

Patient outcomes

During the study period, 90.9% (n=100) of the neonates survived and were discharged, while the mortality rate was 9.1% (n=10).

Statistical highlights

IVC-CI

Significantly higher index was observed in hypovolemic group (46.00±6.14%) compared to septic and cardiogenic groups (p<0.001), reflecting severe volume depletion.

Vascular ratios

The IVC min/AO ratio was notably lower in the hypovolemic shock (46.0±8.0%) compared to septic (54.7±8.0%) and cardiogenic shock (55.0±8.2%) groups (p=0.012).

Table 3: POCUS vascular and echocardiographic findings by shock type.*

Variables	Septic shock, (n=46)	Cardiogenic shock, (n=38)	Hypovolemic shock, (n=26)	P value
IVC status				
Collapsed	28 (60.0)	4 (10.5)	17 (65.4)	0.002
Normal	6 (13.0)	6 (15.8)	9 (34.6)	
Distended	12 (21.0)	28 (73.0)	0 (0.0)	
Vascular measurements†				
IVC minimum (mm)	2.4±0.5	3.2±0.5	2.6±0.5	<0.001
IVC maximum (mm)	3.2±0.6	3.7±0.6	4.3±0.6	<0.001
IVC-CI (%)	30.36±5.98	31.20±6.4	46.00±6.14	<0.001
AO diameter (cm)	5.3±0.8	5.7±0.6	5.9±0.7	<0.001
IVC min/AO ratio (%)	54.7±8.0	55.0±8.2	46.0±8.0	0.012
IVC max /AO ratio (%)	73.4±8.9	74.6±8.3	73.8±9.0	0.167
Left ventricular ejection fraction %	48.5±10.2	39.6±12.5	52.3±9.8	0.003

*P calculated using one-way ANOVA for continuous variables and Chi-square test for categorical variables. P<0.05 was considered to indicate statistical significance. † Plus–minus values are means±SD. AO denotes abdominal aorta, IVC inferior vena cava, and IVC-CI inferior vena cava collapsibility index.

Table 4: Modification of clinical management following POCUS assessment.

Treatment modality	Pre-POCUS	Post-POCUS	P value*
Septic shock, (n=46)			
Fluid resuscitation	35 (76.1)	46 (100)	<0.001
Noradrenaline	18 (39.1)	36 (78.3)	<0.001
Cardiogenic shock, (n=38)			
Fluid resuscitation	38 (100)	16 (42.1)	<0.001
Adrenaline	21 (55.3)	38 (100)	<0.001
Hypovolemic shock, (n=26)			
Fluid resuscitation	12 (46.2)	26 (100)	<0.001
Adrenaline	8 (30.8)	20 (76.9)	<0.001

*P values for categorical variables were calculated using McNemar's test for paired data. POCUS denotes point-of-care ultrasound.

IVC diameter

Differences in both minimum and maximum IVC diameters across the three shock types were highly significant (p<0.001).

DISCUSSION

The transition from fetal to neonatal circulation makes the management of shock in the newborn uniquely challenging. Our study demonstrates that POCUS serves as a critical adjunct to traditional clinical assessment, providing real-time physiological data that significantly alters management strategies. In our cohort of 110 neonates, septic shock was the most prevalent etiology (41.6%), followed by cardiogenic (34.5%) and hypovolemic shock (23.6%). This distribution aligns with findings by Shah et al who also identified sepsis as the leading cause of neonatal circulatory collapse.[19]

A central finding of this study was the utility of the IVC-CI in differentiating shock states. Neonates with hypovolemic shock exhibited a significantly higher mean IVC-CI (46.00±6.14%) compared to those with septic (30.36±5.98%) or cardiogenic shock (31.20±6.4%) (p<0.001). Furthermore, the IVC min /AO ratio was notably lower in the hypovolemic group (46.0±8.0%), reflecting diminished venous return. These results are consistent with El-Nawawy et al who reported that IVC diameters and distensibility indices are feasible non-invasive surrogates for fluid responsiveness in pediatric populations.[20] Conversely, cardiogenic shock was characterized by distended, less collapsible vessels, with significantly higher mean IVC min (3.2±0.5 mm) and IVC max (3.7±0.6 mm) values, likely due to elevated right atrial pressures and impaired myocardial function.

The clinical impact of POCUS was most evident in the immediate modification of treatment. Following POCUS evaluation, fluid resuscitation was appropriately increased in 100% of hypovolemic and septic patients. More importantly, in the cardiogenic shock group, fluid administration was stopped in 57.9% of cases (decreasing from 100% to 42.1% of patients) once POCUS identified signs of volume overload or cardiac dysfunction. This shift is crucial, as volume expansion in the setting of poor myocardial contractility can exacerbate heart failure. These management shifts were statistically significant (p<0.001), underscoring the role of POCUS in preventing potentially harmful interventions.

Our results regarding inotrope selection also showed significant shifts. After POCUS, there was a targeted increase in noradrenaline for septic shock and adrenaline for cardiogenic shock, aligning therapy with the identified pathophysiology rather than relying on empirical "crashing neonate" bundles.[21]

While some literature, such as that by Orso et al and Long et al suggests that IVC variations may not always reliably predict fluid responsiveness in all pediatric contexts, our data suggests that in the specific context of neonatal shock, these measurements provide high diagnostic yield.[22,23] The survival rate in our study was 90%, which is higher than the 64% mortality reported in some earlier studies of neonatal shock, potentially reflecting the benefits of rapid, POCUS-guided hemodynamic stabilization.

Limitations

While this study highlights the utility of POCUS in neonatal shock, several limitations persist. First, the single-center, observational design may limit the generalizability of the findings and precludes a definitive comparison with a randomized control group.

Second, the exclusion of complex cases, such as those with congenital heart disease or surgical conditions, means these vascular profiles may not apply to all neonatal populations.

Third, the lack of long-term follow-up prevents an assessment of whether POCUS-guided stabilization translates into improved neurodevelopmental outcomes post-discharge. Finally, despite standardized training, inter-observer variability in IVC and AO measurements remains a potential source of bias, as results can be influenced by the operator’s technique and the patient's respiratory phase. Future multi-center randomized trials are required to establish standardized, evidence-based POCUS protocols across diverse clinical settings.

CONCLUSION

POCUS provides rapid, bedside hemodynamic assessment in neonates with shock and aids in differentiating underlying etiologies. Its integration into routine NICU practice can facilitate timely, targeted management and may improve clinical outcomes.

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