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Sonographic measurement of inferior vena cava diameter in assessment of volume status in pediatric shock: A prospective observational study.

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Abstract

Background
Accurate assessment of intravascular volume status in pediatric shock remains a clinical challenge, often relying on subjective and invasive methods. Bedside ultrasonography of the inferior vena cava (IVC) has emerged as a promising, non-invasive modality to estimate volume status. This study aimed to evaluate the IVC diameter and IVC-to-aortic (IVC/Ao) ratio as objective indicators of hypovolemia in children using ultrasound.
Objectives: To obtain and analyze data on IVC diameter and IVC/Ao ratio measured by sonography for assessing intravascular volume status in infants and children with clinical shock compared to euvolemic controls.

Methods
In this prospective observational study, 60 children aged 1 month to 18 years admitted with clinical shock were compared with 60 age-matched euvolemic controls. Sociodemographic characteristics, including age and sex, were recorded. Maximum sagittal IVC diameter, transverse aortic diameter, and IVC/Ao ratio were measured using bedside ultrasound.

Results
The mean age of participants was comparable; the male-to-female ratio was 0.6:1 in the shock group and 1:1.2 in controls. The mean IVC diameter was significantly lower in the shock group (0.99±0.45 cm) than in controls (1.46±0.52 cm; p<0.001), indicating intravascular hypovolemia. The IVC/Ao ratio was also reduced in shock cases (0.65±0.10) compared to controls (0.98±0.09; p<0.001). No significant difference was observed in aortic diameters.

Conclusion
Ultrasound-derived measurements of IVC diameter and IVC/Ao ratio are reliable non-invasive indicators of hypovolemia in pediatric shock.

Recommendations
Bedside ultrasound should be integrated into the routine evaluation of children with suspected shock to improve early detection and guide fluid management.

Keywords: *Pediatric Shock, Inferior Vena Cava, Inferior Vena Cava to Aortic Ratio, Ultrasound, Volume Status Assessment*
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Introduction

Shock is a pathophysiological condition marked by a substantial reduction in systemic tissue perfusion, ultimately leading to impaired oxygen delivery to vital organs [1]. Timely and accurate evaluation of intravascular volume status is critical in managing pediatric shock, as it helps guide appropriate volume resuscitation while preventing the complications of fluid overload [2]. Traditional clinical parameters such as skin perfusion, urine output, blood pressure, and central venous pressure are commonly used to estimate volume status. However, these indicators are often delayed due to physiological compensatory mechanisms or may require invasive procedures, limiting their reliability and practicality in acute settings.

Bedside ultrasonography has emerged as a valuable, non-invasive, rapid, and increasingly accessible modality in pediatric intensive care for the assessment of intravascular volume status [3,4]. Initially utilized primarily in cardiology to evaluate tricuspid regurgitation and right heart function, ultrasound assessment of the inferior vena cava (IVC) has now gained traction in critically ill patients for evaluating fluid status [5]. The IVC, being a highly compliant vessel, changes in diameter with respiration and total body fluid volume, making it a dynamic marker of intravascular status.

Among the sonographic parameters, the maximum sagittal IVC diameter and the IVC-to-aortic (IVC/Ao) ratio have shown potential as objective indicators of hypovolemia. These measurements are notably lower in children clinically assessed to be in shock, suggesting their diagnostic utility in differentiating hypovolemic states from euvolemia.

This study aimed to evaluate the role of IVC diameter and IVC/Ao ratio, measured via bedside ultrasound, as objective indicators of volume status in pediatric patients by comparing these values between children in shock and age-matched euvolemic controls.

Methodology

Study design

This study was a hospital-based prospective observational case-control study designed to assess intravascular volume status in pediatric patients with clinical shock using bedside ultrasound measurements.

Study setting

The study was conducted in the Pediatric Intensive Care Unit (PICU) and Pediatric Ward at the Indira Gandhi Institute of Child Health (IGICH), Bangalore, Karnataka, India. IGICH is a tertiary care pediatric referral center equipped with specialized intensive care facilities, providing healthcare services to children from across Karnataka and neighboring states.

Study duration

The study was carried out over 12 months, from January 2017 to December 2017.

Study population

The study included two groups:

Cases: Children aged 1 month to 18 years admitted with clinical signs of shock based on Pediatric Advanced Life Support (PALS) guidelines.
Controls: Age-matched euvolemic children admitted for minor non-critical ailments without any signs of fluid overload or depletion.

Sample size and sample size calculation

A total of 120 children were enrolled in the study, with 60 children in the shock group (cases) and 60 age-matched euvolemic children as controls. The sample size was calculated based on a pilot data set from the institution that showed a mean difference of 0.4 cm in IVC diameters between shocked and non-shocked children. Using a power of 80%, an alpha error of 5%, and an effect size of 0.5, the required minimum sample size was 52 per group. To account for potential dropouts or exclusions, the sample size was increased to 60 per group.

Inclusion criteria

Cases: Children aged 1 month to 18 years, admitted to the Emergency Department or Pediatric Intensive Care Unit (PICU) with clinical features of shock based on the latest Pediatric Advanced Life Support (PALS) guidelines.
Controls: Children of the same age range, admitted to the pediatric ward with no clinical signs of volume overload or depletion.

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Exclusion criteria

Children with the following conditions were excluded from both groups:

- Congenital heart disease
- Vascular malformations
- Diseases affecting vascular compliance
- Multiorgan dysfunction
- Patients who were intubated or mechanically ventilated
- Patients receiving vasoactive medications

Study procedure

All children underwent bedside ultrasonography in the supine position. A curvilinear or phased-array transducer was placed in the subxiphoid region, just caudal to the left renal vein's insertion into the IVC. The liver served as an acoustic window. A transverse view was used to visualize both the inferior vena cava (IVC) and the descending aorta. The maximum anteroposterior (AP) diameters of both vessels were measured during quiet respiration. All measurements were taken by trained clinicians using standardized protocols.

Bias and mitigation

To minimize selection bias, consecutive eligible cases and controls were enrolled prospectively. Measurement bias was reduced by ensuring that all ultrasound measurements were performed by trained clinicians using standardized protocols with the same model of ultrasound equipment. To minimize observer bias, the sonographers were blinded to the clinical diagnosis at the time of measurement. Additionally, cases and controls were matched for age to control for confounding due to vessel size variability across age groups.

Statistical analysis

Descriptive statistics such as mean, standard deviation (SD), and median were used for quantitative variables. The Mann-Whitney U test was applied to assess statistical differences between groups. A p-value <0.05 was considered statistically significant. Statistical analyses were conducted using appropriate software tools for clinical research.

Ethical considerations

The study was approved by the Institutional Ethics Committee of IGICH. Written informed consent was obtained from the parents or legal guardians of all participating children. Patient confidentiality was maintained, and participation was entirely voluntary with the option to withdraw at any time.

Results

A total of 138 patients were assessed for eligibility. After excluding 18 subjects due to various reasons (e.g., not meeting inclusion criteria or incomplete data), 60 children were enrolled in the shock group and 60 age-matched children in the control group.

Primary data analysis

Summary statistics were generated for the participant characteristics (age, sex), vital signs (pulse rate, respiratory rate, capillary refill time, mean blood pressure), urine output, and primary study parameters (maximum sagittal IVC diameter, transverse aortic diameter). The Mann-Whitney U test was applied to find out the significant difference between the two groups in the parameter measured. A total of 138 patients were assessed for eligibility, and 60 pairs of cases and controls were enrolled.

Table 1: Age distribution of study participants

	Age					Total	$\chi 2$ Value	P-Value
	<1 yr	1-5 yrs.	6-10 yrs.	11-15 yrs.	>15 yrs.			
Shock	7	16	17	18	2	60	2.910	0.573
	11.7%	26.7%	28.3%	30.0%	3.3%	100.0%		
Control	10	9	21	18	2	60		
	16.7%	15.0%	35.0%	30.0%	3.3%	100.0%		
Total	17	25	38	36	4	120		
	14.2%	20.8%	31.7%	30.0%	3.3%	100.0%		

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In the shock group, the majority of children (30%) belonged to the 11–15 years age group, while in the control group, the largest proportion (35%) belonged to the 6–10 years age group. The age distribution was comparable between the two groups (p=0.573). The male-to-female ratio in the shock group was 0.6:1, and in the control group was 1:1.2. All cases had fulfilled the criteria of shock with tachycardia, poor perfusion, and hypotension, and no control subjects were hemodynamically unstable in any of these three parameters.

Table 2: Vital parameters of the study population

		N		Mean	SD	Min.	Max.	T-Value	P-Value
Heart Rate (beats/min)	Shock	60		155.65	19.255	110	198	481.658	<0.001
	Control	60		87.18	14.601	65	128		
Respiratory Rate (cycles/min)	Shock	60		42.03	11.821	26	78	109.923	<0.001
	Control	60		23.90	6.305	17	48		
Mean BP (mm of Hg)	Shock	60		57.78	11.016	37	80	139.925	<0.001

The vital signs of the study group at the time of recruitment showed tachycardia, tachypnea, and hypotension, suggesting a clinical state of shock.

Table 3: Maximum sagittal IVC diameter (cms) in different age groups

Age		N	Mean (Min-Max)	SD	Median	P-Value
<1 yr	Shock	7	0.34 (0.3-0.4)	0.053	0.30	*<0.001*
	Control	10	0.68(0.5-0.8)	0.103	0.70	
1-5 yrs	Shock	16	0.69(0.3-0.9)	0.188	0.80	*<0.001*
	Control	9	1.14 (1.0-1.2)	0.073	1.20	
6-10 yrs	Shock	17	1.04 (0.6-1.3)	0.224	1.20	*<0.001*
	Control	21	1.49(1.1-1.8)	0.261	1.60	
11-15 yrs	Shock	18	1.36(1.1-2.1)	0.315	1.20	*<0.001*
	Control	18	1.89(1.6-2.7)	0.367	1.80	
>15 yrs	Shock	2	1.95(1.8-2.1)	0.212	1.95	0.333
	Control	2	2.45 (2.4-2.5)	0.071	2.45	
Max. Sagittal IVC Diameter (Cms)	Shock	60	0.99(0.3-2.1)	0.447	1.00	*<0.001*
	Control	60	1.46(0.5-2.7)	0.523	1.60	
*Mann-Whitney Test						

In the present study, a significant difference was found in IVC diameters between the shock and control groups in each age group.
0–1 year: Difference 0.34 cm (p value <0.001)
1–5 years: Difference 0.45 cm (p value<0.001)
6–10 years: Difference 0.45 cm (p value<0.001)
11–15 years: Difference 0.53 cm (p value<0.001)
>15 years: Difference 0.5 cms (p value 0.333)

When the mean maximum sagittal IVC diameter was compared across all age groups, a significant difference of 0.47 cm was found between the shock and control groups. The reduction in maximum sagittal IVC diameter in the shock group is visually represented in Figure 1, which illustrates the subxiphoid sagittal sonographic measurement of IVC diameter.

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Figure 1: Ultrasound image showing maximum sagittal diameter of the inferior vena cava (IVC).

This image(figure 1) demonstrates the sagittal view of the IVC, captured via subxiphoid sonography. The measured diameter (0.694 cm) represents the anteroposterior dimension during quiet respiration in a pediatric subject with clinical features of shock.

Table 4: Transverse aortic diameter (cms) in different age groups

Age		N	Mean (Min-Max)	SD	Median	P-Value
<1 yr	Shock	7	0.71(0.70-0.80)	0.038	0.70	0.315
	Control	10	0.74(0.40-0.90)	0.143	0.75	
1-5 yrs.	Shock	16	1.04(0.65-1.30)	0.198	1.10	0.043
	Control	9	1.19(1.10-1.30)	0.060	1.20	
6-10 yrs.	Shock	17	1.56(1.10-2.10)	0.320	1.60	0.663
	Control	21	1.50(1.0-1.90)	0.276	1.50	
11-15 yrs.	Shock	18	1.94 (1.60-2.90)	0.373	1.80	0.239
	Control	18	1.86(1.30-2.60)	0.345	1.75	
>5 yrs.	Shock	2	2.60(2.40-2.80)	0.283	2.60	1.000
	Control	2	2.60(2.60-2.60)	0.000	2.60	
Transverse Aortic Diameter (Cms)	Shock	60	1.47 (0.65-2.90)	0.558	1.45	0.973
	Control	60	1.47(0.40-2.60)	0.506	1.45	

There was no significant change in aortic diameter between the study groups across all age groups. When the mean maximum sagittal IVC diameter was compared across all age groups, there was no significant difference between the shock and control groups (Mann-Whitney U = 1788.5, p = 0.973).

Table 5: IVC/Aortic ratio in different age groups

Age		N	Mean (Min-Max)	SD	Median	P-Value
<1 yr	Shock	7	0.47 (0.40-0.57)	0.074	0.42	<0.001
	Control	10	0.93(0.80-1.25)	0.131	0.88	
1-5 yrs	Shock	16	0.65(0.43-0.90)	0.110	0.66	<0.001
	Control	9	0.96(0.83-1.00)	0.063	1.00	
6-10 yrs	Shock	17	0.67(0.46-0.76)	0.079	0.69	<0.001
	Control	21	1.00(0.90-1.20)	0.075	1.00	
11-15 yrs	Shock	18	0.69(0.60-0.76)	0.049	0.71	<0.001
	Control	18	1.01(0.94-1.20)	0.071	1.00	
>15 yrs	Shock	2	0.75(0.75-0.75)	0.000	0.75	0.333
	Control	2	0.94(0.92-0.96)	0.028	0.94	
IVC/Aortic Ratio	Shock	60	0.65(0.40-0.90)	0.104	0.66	<0.001
	Control	60	0.98(0.80-1.25)	0.087	1.00	

In the present study, a significant difference was found in the IVC/aortic ratio between the shock and control groups in each age group. Figure 2 displays the transverse ultrasound image highlighting the anatomical relationship between the IVC and aorta, used to calculate the IVC/Ao ratio, which was significantly reduced in the shock group.

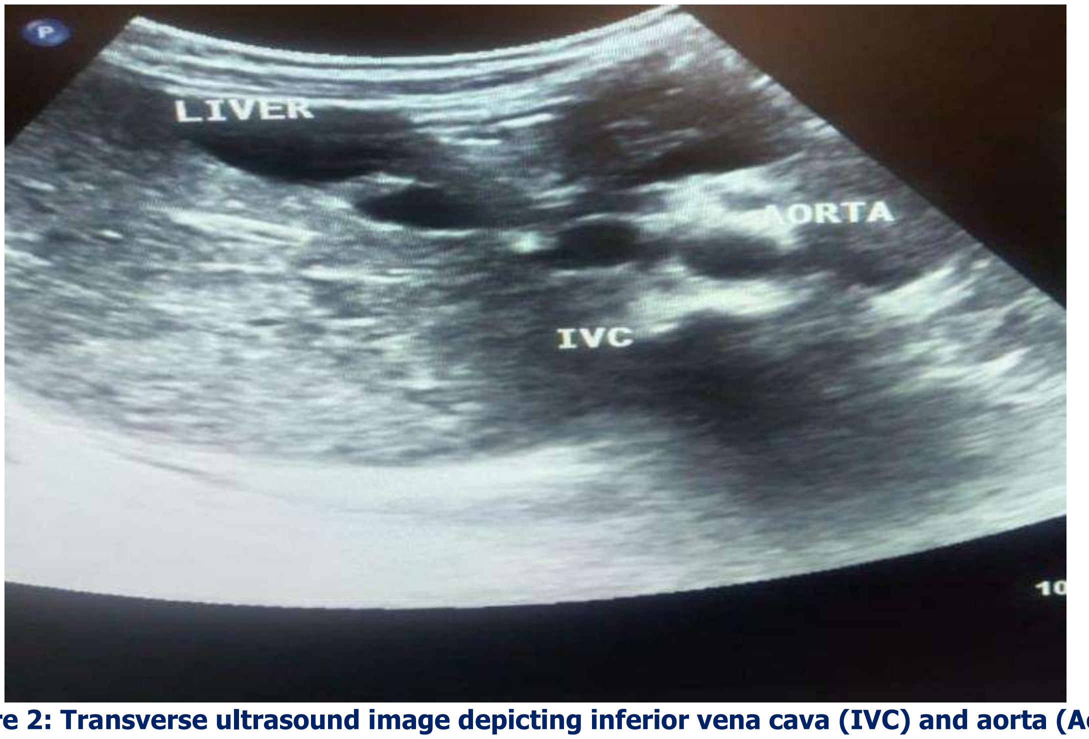

Figure 2: Transverse ultrasound image depicting inferior vena cava (IVC) and aorta (Ao) relative to the liver.

This transverse subxiphoid image(Figure 2) displays the anatomical relationship between the IVC, aorta, and liver. The image illustrates the IVC/Ao ratio, which is significantly reduced in pediatric patients with shock compared to euvolemic controls.

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Table 6: Comparison of max. Sagittal IVC diameter and transverse aortic diameter in cases and controls

		N	Mean	SD	Median	Min.	Max.	Mann-Whitney	P-Value
Max. Sagittal IVC Diameter (Cms)	Shock	60	0.99	0.447	1.00	0.30	2.10	940.0	<0.001
	Control	60	1.46	0.523	1.60	0.50	2.70		
Transverse Aortic Diameter (Cms)	Shock	60	1.47	0.558	1.45	0.65	2.9	1788.5	0.973
	Control	60	1.47	0.506	1.45	0.4	2.6		

0-1 year: Difference 0.46 (p-value<0.001).
1–5 years: Difference 0.31 (p-value<0.001).
6–10 years: Difference 0.33 (p-value<0.001).
11–15 years: Difference 0.32 (p-value<0.001).
>15 years: Difference 0.19 (p-value = 0.33).

In the present study, a significant difference of 0.33 cm (p <0.001) was found in the mean IVC/ aortic ratio between the shock and control groups.

Discussion

In this prospective observational study, 60 pairs of children were evaluated to compare IVC diameters and IVC/aortic (IVC/Ao) ratios between pediatric patients in shock and age-matched euvolemic controls. All cases were children aged 1 month to 18 years admitted to the pediatric intensive care unit of the Indira Gandhi Institute of Child Health, Bangalore.

This study introduced the IVC/Ao ratio as a novel parameter for assessing volume status. Since vessel diameter varies with age, sex, weight, and body surface area, comparing IVC size with the relatively stable aortic diameter (due to its lower compliance) may yield a more standardized measurement [6,7].

Bedside ultrasonography is an increasingly accessible, non-invasive, and objective method to assess intravascular volume in pediatric settings [8,9]. Historically, IVC assessment was limited to cardiology for evaluating tricuspid regurgitation and right heart function or estimating dry weight in hemodialysis patients [10,11]. More recently, it has been applied to acutely ill patients to evaluate hypovolemia and guide fluid resuscitation [12–14].

Several studies have confirmed the correlation between IVC measurements and volume status, especially in adults [15]. In our study, the IVC/Ao ratio remained consistent among euvolemic controls across age groups, suggesting its reliability. We found the mean sagittal IVC diameter in shock patients was 0.99 cm compared to 1.46 cm in controls ($p < 0.001$). The IVC/Ao ratio in the shock group was 0.65, while in controls it was 0.98 ($p < 0.001$).

These findings align with prior research. A difference of 0.8 cm was reported between adult patients with low and high central venous pressure [16]. A trauma-based study reported a 0.63 cm difference between hypotensive and normotensive adults [12]. Pediatric research on dehydration revealed a 0.37 cm difference pre- and post-rehydration [17]. A systematic review confirmed IVC diameter as a reliable indicator of volume status [18].

Our findings were comparable to those of other pediatric studies [19]. One study involving hemorrhagic shock demonstrated that transabdominal ultrasound was more accurate than traditional shock indices in estimating blood loss [20]. Another study evaluating gastroenteritis-related dehydration in children found the IVC/Ao ratio measured by bedside ultrasound to be a marginally accurate indicator [8].

In trauma patients, the IVC diameter also correlated with hemorrhagic shock severity, and ultrasound outperformed clinical indices like heart rate and blood pressure [21]. In another prospective trauma study, IVC collapsibility was significantly higher in shocked patients, suggesting it could complement the FAST examination in trauma settings [22].

A study evaluating mechanically ventilated septic patients showed that the respiratory variation in IVC diameter (distensibility index) was a reliable predictor of fluid responsiveness. The cardiac index improved significantly in patients with greater baseline IVC variation, supporting the role of dynamic IVC measures [23].

Generalizability

The findings of this study suggest that bedside ultrasound measurement of the inferior vena cava diameter and IVC-to-aortic ratio can serve as reliable, non-invasive indicators of intravascular volume status in pediatric patients with shock. Although the study was conducted in a single tertiary care center, the physiological principles underlying the association between IVC size and volume status are universal and can be applied to other pediatric

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intensive care settings. Therefore, the results may be generalizable to similar healthcare environments with access to ultrasound technology, particularly in low-resource settings where non-invasive and rapid assessment tools are highly valuable. However, larger multicenter studies are necessary to confirm these findings across diverse populations and healthcare systems.

Conclusion

In conclusion, accurately assessing volume status in pediatric shock within acute care settings remains a clinical challenge due to the subjective nature and invasiveness of traditional indicators. Bedside ultrasound emerges as a valuable tool, offering a rapid, painless, non-invasive, and cost-effective alternative. This study demonstrated that children with clinical signs of hypovolemia and shock consistently exhibited significantly lower maximum sagittal IVC diameters and IVC/aortic ratios compared to age-matched euvolemic controls. These findings highlight the utility of ultrasonographic measurements as reliable markers for intravascular volume assessment. Incorporating IVC measurements into routine evaluation may enhance timely and objective decision-making in the management of pediatric shock.

Limitations

The study was limited by its single-center design and relatively small sample size, which indeed affect the generalizability of the findings to wider pediatric populations. Operator dependency in ultrasound measurements and the exclusion of critically ill ventilated patients may have influenced results. Additionally, the study did not evaluate dynamic changes in IVC diameter with respiration or post-resuscitation.

Recommendations

Based on the study findings, it is recommended that bedside ultrasonographic assessment of the IVC diameter and IVC/aortic ratio be incorporated into the routine evaluation of pediatric patients with suspected shock. Training healthcare providers in point-of-care ultrasound can enhance early detection of hypovolemia and guide fluid resuscitation decisions. Future multicenter studies with larger sample sizes are necessary to validate these findings and establish age-specific reference values. Additionally, dynamic assessments of IVC collapsibility with respiration should be explored to further improve diagnostic accuracy in different clinical scenarios.

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List of abbreviations

IVC – Inferior Vena Cava
Ao – Aorta
IVC/Ao ratio – Inferior Vena Cava to Aorta Ratio
PICU – Pediatric Intensive Care Unit
IGICH – Indira Gandhi Institute of Child Health
PALS – Pediatric Advanced Life Support
AP – Anteroposterior
ML – Mediolateral
FAST – Focused Assessment with Sonography for Trauma
CVP – Central Venous Pressure
SD – Standard Deviation

Source of funding

The study had no funding.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

VV-Concept and design of the study, results interpretation, review of literature, and preparing the first draft of the manuscript. Statistical analysis and interpretation, revision of manuscript. SN-Concept and design of the study, results interpretation, review of literature, and preparing the first draft of the manuscript, revision of the manuscript.MSH-Review of literature and preparing the first draft of the manuscript. Statistical analysis and interpretation. MG-Concept and design of the study, results interpretation, review of literature, and preparing the first draft of the manuscript. Statistical analysis and interpretation, revision of manuscript.BGV-

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Design of the study, results interpretation, review of literature, and preparing the first draft of the manuscript. Statistical analysis and interpretation, revision of the manuscript

Data availability

Data is available on request.

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