The Role of the inferior vena cava collapsibility index in management and follow up of pediatric shocked patients

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Abstract

Background:

Ultrasound-guided fluid evaluation, particularly the assessment of inferior vena cava (IVC) parameters, has gained attention in the management of pediatric shock patients. The IVC collapsibility index (IVCCI) is a non-invasive method for evaluating intravascular volume status in critically ill children.

Aim of the Study: this study aimed to evaluate the utility of the IVC collapsibility index as a non-invasive tool for assessing intravascular volume status in pediatric patients with hypovolemic, septic, and cardiogenic shock. Additionally, the study explored its potential to differentiate between these types of shock.

Patients and Methods: a prospective observational study was conducted on 116 pediatric patients (aged 1 day to 15 years) admitted to Assiut University Hospital with hypovolemic, septic, or cardiogenic shock. IVC diameters were measured at the end of inspiration and expiration, and the IVC collapsibility index was calculated. Measurements were taken on admission and repeated on the third day after shock management. Data were compared to established normal values in literature.

Results: In cardiogenic shock patients, IVC diameters were significantly lower on day three compared to admission, resulting in a higher collapsibility index. Conversely, hypovolemic shock patients exhibited the opposite trend. No significant changes were observed in septic shock patients. The IVC collapsibility index was significantly higher in hypovolemic and septic shock patients compared to cardiogenic shock patients on admission.

Conclusion: the IVC collapsibility index is a reliable, non-invasive tool for assessing intravascular volume status in pediatric shock patients. It can differentiate between hypovolemic and cardiogenic shock and may aid in monitoring fluid responsiveness.

Keywords: Inferior vena cava collapsibility index, fluid responsiveness, pediatric shock, ultrasound.

Introduction

Hemodynamic monitoring is critical in the management of critically ill pediatric patients, particularly those in shock. Accurate assessment of intravascular volume status is essential for effective shock management. However, traditional methods such as central venous pressure

(CVP) measurement and laboratory tests are invasive and may not always be feasible in pediatric settings [1, 2].

Point-of-care ultrasonography (POCUS) has emerged as a valuable tool in pediatric emergency medicine, offering a non-invasive, rapid, and objective method for assessing volume status [3, 4]. Among the dynamic measures, the IVC collapsibility index (IVCCI) has gained popularity due to its simplicity and reliability in estimating intravascular volume status [5].

The IVC's diameter varies with changes in intravascular pressure, making it a useful indicator of volume status. The IVCCI, calculated as the change in IVC diameter during the respiratory cycle, correlates with CVP and has been proposed as a non-invasive alternative for assessing fluid responsiveness [6, 7]. Studies have shown that a CVP threshold of less than 8 mmHg, often used to guide fluid resuscitation in adults, correlates closely with an IVCCI of ≥ 50% [8].

This study aimed to evaluate the role of IVCCI in the early diagnosis and management of pediatric shock, particularly in differentiating between hypovolemic, septic, and cardiogenic shock. By comparing IVCCI values in these shock types, we sought to determine its utility as a non-invasive tool for guiding fluid therapy and monitoring patient response.

Patients and Methods

Study Design:

This prospective observational study was conducted at Assiut University Hospital from October 2018 to October 2019. The study included 116 pediatric patients aged 1 day to 15 years presenting with hypovolemic, septic, or cardiogenic shock. Patients requiring immediate resuscitation, those who received more than 20 ml/kg of IV fluid prior to admission, and those with increased intra-abdominal or intra-thoracic pressure were excluded.

Inclusion Criteria:

1-Age: 1 day to 15 years

2-Diagnosis of hypovolemic, septic, or cardiogenic shock

3-Not mechanically ventilated

Exclusion Criteria:

1-Patients requiring immediate resuscitation

2-Patients with increased intra-abdominal or intra-thoracic pressure

3-Morbid obesity or severe orthopnea

Ultrasonographic Measurements:

IVC diameters were measured using a 2-5 MHz convex probe (Philips EnVisor).

To get clear images, a sterile ultrasonic gel was applied to the transducer at room temperature. The Sagittal section imaging of the IVC was done. The liver was employed as an auditory window and the probe was positioned in the subxiphoid region to produce a sagittal image.

While the probe was positioned in the subxiphoid region, pictures of the IVC emptying into the right atrium were captured. M mode was used to capture the IVC's diameters on inspiration and expiration.

Measurements were taken at the end of inspiration and expiration, and the IVC collapsibility index was calculated as follows:

$$IVCCI = IVC\ max - IVC\ min \div IVC\ max \times 100$$

Measurements were repeated on the third day of admission after shock management.

Table 1: Echocardiographic measurements of the IVC indices for each age group [9]

	Overall (n = 516)	**Age<l (n = 54)**	**1 <age<4 (n = 75)**	**4<age<7 (n=117)**	**7<age< 10 (n=95)**	**10<age<13 (n = 99)**	**13 < age<16 (n = 76)**
IVC max (mm)	11.6 (4.9)	5.0 (1.2)	8.1 (2.7)	9.7 (2.4)	12.5 (3.4)	14,5 (3,5)	17.9 (4.0)
IVC min (mm)	8.2 (4.4)	3.2 (1.1)	5.3 (2.7)	6.7 (2.6)	8.85(3.3)	10.4 (4)	13.5(4.2)
AOs (mm)	11.1 (3.4)	6.3 (1.3)	8.7 (1.6)	9.8 (1.7)	11.9 (2.2)	13.5 (2.8)	15.0 (2.9)
CI (%)	31 (17)	36(16)	36 (18)	31 (17)	30(17)	30 (16)	25(13)
IVC max/AOs	1.03 (0.28)	0.83 (0.20)	0.92 (0.19)	0.99 (0.22)	1.07 (0.30)	1.10 (0.27)	1.22 (0.31)

IVC max: inferior vena cava maximum diameter(expiratory) IVC min: inferior vena cava minimum diameter(inspiratory)

AOs: aorta diameter CI: collapsibility index

Ethical considerations:

The Research Ethics Committee of the Faculty of medicine at Assuit University in Egypt, gave its approval to the study procedure, and registered in clinical trials with IRP (04-2023-100105). All participants gave their informed consent to participate in the study and generalize the results after being fully aware of its techniques and goals. The study was conducted in accordance with the Helsinki Declaration

Statistical Analysis:

Data was analyzed using IBM SPSS Statistics version 22. Continuous variables were expressed as mean ± standard deviation or median (range), while categorical variables were expressed as frequencies and percentages. Non-parametric tests (Mann-Whitney U test, Kruskal-Wallis test) were used for group comparisons. A p-value < 0.05 was considered statistically significant.

Results: tables (2,3 and 4)

IVC Diameters and Collapsibility Index: table

Cardiogenic Shock: IVC diameters were significantly lower on day three compared to admission, resulting in a higher collapsibility index ($p < 0.05$).

Hypovolemic Shock: IVC diameters increased significantly by day three, with a corresponding decrease in the collapsibility index ($p < 0.001$).

Septic Shock: No significant changes in IVC diameters or collapsibility index were observed ($p > 0.05$).

Comparison of Shock Types:

On admission, hypovolemic and septic shock patients had significantly higher collapsibility indices compared to cardiogenic shock patients ($p < 0.001$). However, by day three, no significant differences were observed between the groups.

Collapsibility Index as a Predictor: 73.7% of hypovolemic shock patients had a collapsibility index > 36%. 81.1% of cardiogenic shock patients had a collapsibility index ≤ 36%. 55.6% of septic shock patients had a collapsibility index > 36%.

Table 2: Ultrasonographic measurements in the third day compared to those on admission which remained until the third day in different types of shock

	Cardiogenic (n=11)	**Hypovolemic (n=19)**	**Septic (n=9)**
IVC max (mm)			
On admission	8.0 (4.5-23.0)	3.2 (2.0-7.2)	4.3 (2.0-15.8)
Day 3	7.1 (3.7-20.0)	5.0 (2.5-8.0)	4.0 (3.0-11.2)
P value*	**#0.01**	**#<0.001**	0.93
IVC min (mm)			

On admission	5.2 (2.0-18.0)	2.1 (1.0-6.0)	3.1 (1.0-8.1)
Day 3	4.1 (2.0-15.0)	3.5 (1.1-7.2)	3.0 (1.2-7.1)
P value*	**#0.005**	**#<0.001**	0.85
Collapsibility index			
On admission	22.0 (10.0-60.0)	45.0 (7.0-66.0)	41.0 (14.0-66.0)
Day 3	27.0 (13.8-54.0)	33.0 (10.0-60.0)	33.0 (22.0-60.0)
P value*	**#0.04**	**#0.05**	0.37
AOs (mm)			
On admission	6.5 (5.0-24.0)	6.0 (3.0-9.5)	6.1 (3.0-11.7)
Day 3	6.3 (6.0-23.0)	6.0 (1.5-9.5)	6.0 (1.5-10.0)
P value*	0.87	0.11	0.30
C/A Index			
On admission	0.9 (0.6-1.6)	0.6 (0.4-0.7)	0.8 (0.5-1.3)
Day 3	0.9 (0.6-1.2)	0.8 (0.4-1.0)	0.7 (0.5-1.1)
P value*	0.08	**#0.004**	0.90

Data are reported as median (range) * Wilcoxon singed-rank test # Means significant

IVC max: inferior vena cava maximum expiratory diameter, IVC min: inferior vena cava minimum inspiratory diameter, AOs: Aorta systolic diameter, C/A: IVC max/ Aorta systolic diameter

Table (3): Ultrasonographic measurements of all children on admission and in the third day in relation to the type of shock:

Variables	**Cardiogenic**	**Hypovolemic**	**Septic**	**p-value***	**p-value 1**	**p-value 2**	**p-value 3**
On admission (n=116)	**n=37**	**n=40**	**n=39**				
IVC max (mm)	5.8 (2.8-23.0)	4.0 (2.0-8.0)	5.5 (2.0-15.8)	**# 0.001**	**#<0.001**	0.10	0.20
IVC min (mm)	4.8 (0.7-18.0)	2.5 (1.0-6.0)	3.0 (1.0-8.8)	**#<0.001**	**#0.001**	**#<0.001**	0.13
Collapsibility index	20.0 (0.0-66.0)	42.0 (7.0-66.0)	50.0 (14.0-66.0)	**#<0.001**	**#<0.001**	**#0.001**	0.06
AOs (mm)	6.2 (3.1-25.0)	6.0 (3.0-11.0)	6.1 (3.0-12.0)	0.471	0.13	0.17	1.0
C/A Index	0.9 (0.6-1.6)	0.6 (0.4-1.5)	0.8 (0.42-1.7)	**#<0.001**	**#<0.001**	0.44	**#0.004**
Day 3 (n=39)	**n=11**	**n=19**	**n=9**				
IVC max (mm)	7.1 (3.7-20.0)	5.0 (2.5-8.0)	4.0 (3.0-11.2)	0.065	**#0.03**	0.09	1.00
IVC min (mm)	4.1 (2.0-15.0)	3.5 (1.1-7.2)	3.0 (1.2-7.1)	0.115	**#0.03**	0.11	1.00
Collapsibility index	27.0 (13.8-54.0)	33.0 (10.0-60.0)	33.0 (22.0-60.0)	0.170	0.35	1.00	1.00
AOs (mm)	6.3 (6.0-23.0)	6.0 (1.5-9.5)	6.0 (1.5-10.0)	0.075	0.09	0.11	1.00
C/A Index	0.9 (0.6-1.2)	0.8 (0.4-1.0)	0.7 (0.5-1.1)	0.135	0.10	0.97	1.00

Data are reported as median (range) # means significant

* Kruskal-Wallis Test and pair wise comparison between groups

P value *: comparison between the three type of shock

P value 1: comparison between cardiogenic and hypovolemic shock

P value 2: comparison between cardiogenic and septic shock

P value 3: comparison between hypovolemic and septic shock

Table 4: Collapsibility Index in different types of shock in all children on day 3 after control of shock(n=39)

	Collapsibility Index		**p-value***
	≤ 36%	**> 36%**	
Type of shock			#0.016
Cardiogenic	9 (81.1%)	2 (18.9%)	
Hypovolemic	5 (26.3%)	14 (73.7%)	
Septic	4 (44.4%)	5 (55.6%)	

Discussion

The IVC collapsibility index (IVCCI) has emerged as a valuable, non-invasive tool for assessing intravascular volume status in pediatric shock patients. Our study demonstrates that IVCCI can effectively differentiate between hypovolemic and cardiogenic shock, with higher indicating volume depletion and lower indices suggesting volume overload. These findings are consistent with several previous studies, while also highlighting areas of divergence that warrant further investigation.

Our findings align with those of Stawicki et al. (2014) [6], who proposed that the IVCCI closely correlates with central venous pressure (CVP) and can differentiate between volume-depleted and volume-overloaded states. They found that a collapsibility index > 50% was indicative of hypovolemia, while an index < 15% suggested fluid overload, which is consistent with our observation that hypovolemic shock patients had significantly higher IVCCI values compared to cardiogenic shock patients.

Weekes et al. (2011) [2] reported that IVCCI values were significantly higher in patients with volume loss, which supports our findings that hypovolemic shock patients exhibited higher collapsibility indices on admission. Similarly, Vaish et al. (2017) [7] found a positive correlation between IVC diameters and CVP in pediatric patients, further validating the use of IVCCI as a non-invasive measure of volume status.

Our observation that cardiogenic shock patients had lower IVCCI values on admission is consistent with the findings of Blehar et al. (2009) [9], who demonstrated that an IVCCI ≤ 15% was highly sensitive and specific for diagnosing acute decompensated heart failure. This suggests that the IVCCI can serve as a useful prognostic marker in cardiogenic shock, particularly in identifying patients with fluid overload.

Mannarino et al. (2019) [8] provided reference values for IVC diameters and collapsibility indices in healthy children, which were used as a benchmark in our study. Their findings that IVCCI values > 36% are indicative of hypovolemia align with our results, where 73.7% of hypovolemic shock patients had IVCCI values above this threshold.

Our study found no significant changes in IVC diameters or collapsibility indices in septic shock patients, which contrasts with the findings of Long et al. (2018) [10]. They reported that IVCCI could predict fluid responsiveness in pediatric sepsis patients, although their study included mechanically ventilated patients, which may account for the discrepancy. The complex pathophysiology of septic shock, involving both hypovolemia and vasodilation, may also explain the lack of significant changes in IVCCI in our cohort.

While our study excluded mechanically ventilated patients, Byon et al. (2013) [11] found that IVCCI was a poor predictor of fluid responsiveness in mechanically ventilated children. This suggests that the utility of IVCCI may be limited in certain patient populations, particularly those on mechanical ventilation, where respiratory variations in IVC diameter may be influenced by positive pressure ventilation.

Corl et al. (2012) [12] and Weekes et al. (2012) [13] both reported that IVCCI had limited predictive value for fluid responsiveness in emergency department patients. These findings contrast with our results, where IVCCI effectively differentiated between hypovolemic and cardiogenic shock. However, it is important to note that these studies were conducted in adult populations, and the predictive value of IVCCI may differ in pediatric patients. While our study used a cutoff of 36% for IVCCI based on Mannarino et al. (2019) [8], other studies have proposed different thresholds. For example, Muller et al. (2012) [14] suggested that an IVCCI > 40% is a reliable predictor of fluid responsiveness in spontaneously breathing patients, while an IVCCI < 15% indicates fluid non-responsiveness. This variability in cutoff values highlights the need for standardized reference ranges for pediatric populations.

Limitations and Future Directions

Our study has several limitations. First, the exclusion of mechanically ventilated patients limits the generalizability of our findings to this population. Second, the small sample size, particularly in the septic shock group, may have reduced the statistical power to detect significant changes in IVCCI. Finally, the lack of standardized reference values for IVCCI in pediatric patients underscores the need for larger, multicenter studies to establish definitive cutoff points for fluid responsiveness.

Conclusion

The IVC collapsibility index is a reliable, non-invasive tool for assessing intravascular volume status in pediatric shock patients. It may differentiate between hypovolemic and cardiogenic shock, with higher indices indicating volume depletion and lower indices suggesting fluid overload. However, its role in septic shock and mechanically ventilated patients remains less clear and warrants further investigation. Future studies should focus on establishing standardized reference values and cutoff points for fluid responsiveness in pediatric populations.

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