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RESEARCH **Open Access**

IVC collapsibility indices in assessment of volume overload in neonatal cardiac patients

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Abstract

Background Fluid overload is associated with increased morbidity and mortality in critically ill patients. An accurate assessment of fluid status in neonatal cardiac pediatric patients is required for assessment of fluid overload. Estimation of fluid status using different Doppler parameters may be helpful in determination of fluid status.

Purpose To evaluate difference in fluid status in neonates with and without congenital heart diseases. To detect sensitivity of Doppler Ultrasound in early determination of fluid status. To compare between different parameters (IVC diameter, IVCCI, and IVC/AO ratio) between cardiac and healthy neonates.

Methods Transabdominal Doppler parameters of 25 full-term newborns with congenital heart diseases and congestive heart failure were compared to 25 post-natal age and sex-matched normal healthy neonates serving as controls. Aortic as well as inspiratory and expiratory inferior vena cava diameters were measured. Subsequently, inferior vena cava collapsibility index (IVCCI) and inferior vena cava-to-aortic ratio (IVC/AO) were calculated.

Results Fluid overload detected by increased IVC diameter (decreased IVCCI and increased IVC/AO ratio) was observed in the cardiac compared to the control group. There was positive correlation between the fluid volume and the IVC diameter and IVC/AO ratio and negative correlation with the IVC collapsibility indices.

Conclusions Fluid overload with increased IVC diameter and lack of IVC collapsibility were observed in neonates with congenital heart diseases and congestive heart failure compared with those hemodynamically stable controls. We recommend the use of IVC diameter, IVCCI, and IVC/AO ratio as rapid, easy and sensitive parameters in assessing volume status.

Keywords IVCCI, Fluid overload, Trans abdominal doppler ultrasound, Full term, Congenital heart diseases

Background

Newborns and children alike are especially vulnerable to changes in the body's fluid volume brought on by different medical conditions. Extracellular fluid (ECF), which makes up 1/3 of total body water (TBW), and intracellular fluid (ICF), which makes up 2/3 of TBW, are the two components of TBW. A few compartments make up the ECF space: transcellular fluid (fluid found in the lumen of structures covered in epithelium), interstitial fluid (which surrounds all cells except blood cells), and plasma volume. A neonate's daily fluid exchange can reach 25% of total body weight (TBW), whereas an adult's daily fluid exchange is closer to 6%. Consequently, the clinical manifestation of dehydration in newborns is more striking [1].

A modest amount of fluid will lead to ischemia, increase organ failure, and promote tissue hypoperfusion. Conversely, an excess of fluid impedes the supply of oxygen, worsens the results of treatment, causes more problems, and lengthens the duration of stay in critical care as well as the death rate [2]. A wide range of techniques are available to measure intracellular

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water content, ranging from sophisticated invasive procedures like pulmonary catheterization to a clinical assessment of vital signs [3].

An extensible and collapsible vessel with a high capacitance is the IVC. Its lower diameter and easy collapsibility result from this volume depletion. Replaced fluid causes the diameter to expand and collapsibility to decrease (Fig. 1). The flexibility of the veins reaches a threshold when there is an excess of fluid in them. This threshold prevents the veins from collapsing and keeps their diameter relatively constant. Individual differences in IVC size mean that it is not well correlated with either body surface area (BSA) or BMI. Furthermore, there are no established reference values for IVC diameter in the pediatric population [4].

Changes in breathing (alterations in intrathoracic and intra-abdominal pressure) and the presence of fluid shortage have a significant impact on the IVC diameter. However, the Ao diameter has low compliance when compared to IVC compliance, meaning that it is believed to be rather steady in every child, even when they are dehydrated [2].

Clinicians in the acute care setting can receive information on abnormal volume status through the pediatric ultrasound measurement of the inferior vena cava (IVC) and aorta (AO), with the study of the collapsibility index (CI) and of the IVC-to-AO ratio (IVC/AO). However, one of the main limitations is the absence of reference normal values by body surface area (BSA) and age [5].

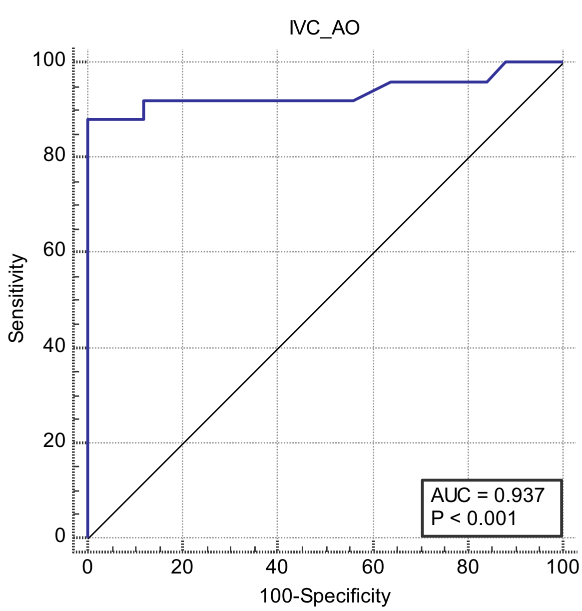

Fig. 1 ROC curve for IVC/Ao value to discriminate patients ($n = 25$) from control ($n = 25$)

Methods

Patients

This study was conducted at Abu-El-Rish Pediatric Hospital, Cairo University, from July 2022 till January 2023.

It included two groups 25 full-term neonates with congenital heart diseases and congestive heart failure aged from 3 to 30 days old, admitted at the neonatal intensive care unit and 25 full-term neonates with no perinatal complications as a control group aged from 3 to 30 days old. A written consent was obtained from the legal guardians of patients before enrollment in the study.

Exclusion criteria Other causes of hypervolemic fluid status (renal or hepatic failure) or dehydrated patients or factors increasing intra-abdominal pressure (ascites and abdominal masses)

Methods

All patients were subjected to

- Full history and clinical examination were taken with emphasis on: age, sex, weight, height diagnosis, and cardiovascular manifestations as well as echocardiography findings.
- Transabdominal ultrasound and Doppler

All sonographic examinations were performed bed side at the neonatal intensive care unit at Children's hospital, Cairo University.

Devices

All ultrasound studies were performed by one investigator using (CANON XARIO-100) ultrasound device that is equipped by 11 MHz Linear array probe.

Technique of examination

Patient position

The patient lies supine.

Subcostal view:

- In both the transverse and longitudinal planes, the ultrasonography linear array probe was positioned in the substernal region using the B-mode.
- The inferior vena cava (IVC), whose anterior and posterior walls run parallel to one another, was investigated in the intrahepatic region under the confluence of the hepatic veins.
- The abdominal aorta was evaluated with the probe positioned in the sub-sternal area in the transverse plane in B-mode. Color Doppler and spectral wave were applied to confirm the vascular anatomy where

the inferior vena cava runs to the right of abdominal aorta.

- The abdominal aorta was measured 5–10 mm above the celiac trunk using a B-mode probe in the sub-sternal area. The IVC was measured in the intrahepatic section below the confluence of hepatic veins using the same probe. The IVC/Ao ratio was calculated by dividing the maximal A-P diameters of the IVC and aorta.

Right lateral transabdominal coronal view:

1. 1. Position the patient supine and point the orientation marker cranially. Move the probe laterally to the patient's right, starting at the sub-sternal area and moving along the lower ribs until the hand hits the bed. The probe was then angled anteriorly, comparable to the angle utilized to see the kidney. It may be useful to picture aiming just anterior to the spine, where the IVC is shown crossing the diaphragm just inferior to the heart and passing into the liver. Traversing the abdomen, the aorta flows parallel to the IVC, farther from the probe.
2. 2. M-Mode was applied. The inferior vena cava was then measured during the breathing phases, taking into account the vein's largest (expiration) and smallest (inspiration) dimensions (its two diameters).
3. The IVCCI was calculated using the equation:

$$\text{IVCCI} = \frac{\text{D max} - \text{D min}}{\text{D max}}$$

Statistical method

Data were entered into the computer and analyzed with the IBM SPSS software package version 25.0. Qualitative data were described using numbers and percentages. The Kolmogorov–Smirnov test was employed to ensure that the distribution was normal. The quantitative data were described using range (minimum and maximum), mean, standard deviation, median, and interquartile range (IQR). The significance of the acquired results was assessed at the 5% level.

The tests used were:

1. *Student's t test* For normally distributed quantitative variables, to compare between two studied groups.
2. *Mann–Whitney test* For abnormally distributed quantitative variables, to compare between two studied groups
3. Receiver operating characteristic curve (ROC)
   It is generated by plotting sensitivity (TP) on Y-axis versus 1-specificity (FP) on X-axis at different cut-off values. The area under the ROC curve denotes the diagnostic performance of the test. Area more than 50% gives acceptable performance, and area about 100% is the best performance for the test. The ROC curve allows also a comparison of performance between two tests.
4. *Spearman correlation* between quantitate variables was done by Spearman correlation.

Results

- Anthropometric measurement data (height (cm), weight (gm), and BMI) were insignificantly different between the studied groups.

Discussion

Central venous pressure is a hallmark of monitoring fluid status in critically ill pediatric patients, and earlier research has validated the use of IVC dimensions to estimate CVP [6]. The collapse of the IVC during the respiratory cycle may be a more sensitive predictor of fluid status in spontaneously breathing patients [7].

Although there is a large range of the literature on adult patients, investigations on pediatric patients and neonates are still restricted; nonetheless, a rising number of studies appear promising [8].

We found that Inferior vena cava (IVC) diameter was increased significantly in cases (5.40 ± 1.29) and ranged between 3.10 and 8.40 compared to control group (3.45 ± 0.71) ($P < 0.001$) indicating IVC diameter associated with increase in fluid volume (Table 1).

In the same line [9], patients with different types of heart illness either had a central venous catheter in the intensive care unit or underwent cardiac catheterization; the maximal (IVCD max; 7.50 ± 3.00) and minimum (IVCD min; 4.65 ± 2.86) IVC diameters showed a strong correlation with CVP.

In their study [10], the hypervolemic group had a significantly greater IVC (minimum diameter) ($p < 0.001$) (Table 2).

Table 1 Inferior vena cava (IVC) and aorta (AO) diameter data in the two studied groups

	Control (*n* = 25)	Cases (*n* = 25)	Test of Sig	*p*
Inferior vena cava (IVC)				
Mean ± SD	3.45 ± 0.71	5.40 ± 1.29	*t* = 6.610	< 0.001
Aorta (AO)				
Mean ± SD	5.14 ± 0.69	4.84 ± 0.93	*t* = 1.278	0.207

Inferior vena cava (IVC) diameter was increased significantly in case (5.40 ± 1.29) compared to control group (3.45 ± 0.71) (P < 0.001). However, aorta (AO) diameter was insignificantly different between the studied groups

Table 2 IVC/AO ratio in the two studied groups

	Control (*n* = 25)	Cases (n = 25)	Test of Sig	*p*
IVC/AO				
Mean ± SD	0.67 ± 0.12	1.07 ± 0.25	*U* = 39.50	< 0.001

IVC/AO ratio was significantly higher in patients (1.07 ± 0.25) than in control (0.67 ± 0.12) due to increased IVC level in patients

The current study found no significant difference in aorta (AO) diameter between the analyzed groups (4.84 ± 0.93 in patients and 5.14 ± 0.69 in controls). The findings can be explained as: The IVC is a thin-walled, collapsible vessel whose size varies with intravascular volume. In comparison, the aorta (Ao) is a thick-walled conduit that does not appreciably vary in size with variations in intravascular blood volume [11].

In the current study, we found that IVC collapsibility index was decreased significantly in the cases with mean of (0.20 ± 0.09) compared to the control group as its IVCCI mean was (0.53 ± 0.10) ($P < 0.001$) (Table 3, Fig. 2). In the same line [12], the study included ill neonates who needed rigorous hemodynamic monitoring, and umbilical vein catheterization was used to quantify CVP. Ultrasound was used to measure both IVC diameters and IVCCI. The patients were classified into three categories based on CVP: hypovolemic (CVP < 8 cmH2O), euvolemic (CVP 5–8 cmH2O), and hypervolemic (CVP > 8 cmH2O). The IVCCI in neonates with hypovolemic state was > 55 (mean 62.39 ± 6.005), euvolemia was between 20 and 55, and hypervolemic neonates were < 20 (mean 11.27 ± 4.71).

Similarly to our study findings, a recently published study by [13], of 30 full-term babies with cardiogenic shock were compared to 30 full-term hemodynamically stable neonates. The IVCCI in neonates with cardiogenic shock was 32.78%, significantly lower than the healthy controls' 50.11%.

Studies among neonates by [8] illustrated that the closer the collapsibility index is to 0% or 100%, the higher the likelihood that the patient is volume overloaded or depleted, respectively [13], healthy neonatal controls IVCCI were [50.11%], and also, in [12], euvolemic neonates had IVCCI in (20–55%), in agreement with our control. Furthermore, [5], The study tested 516 healthy

Table 3 IVCCI in the two studied groups

	Control (*n* = 25)	Cases (*n* = 25)	Test of Sig	*p*
IVCCI				
Mean ± SD	0.53 ± 0.10	0.20 ± 0.09	*U* = 11.50	< 0.001

IVCCI was decreased significantly in the cases group compared to the control group (*P* = < 0.001)

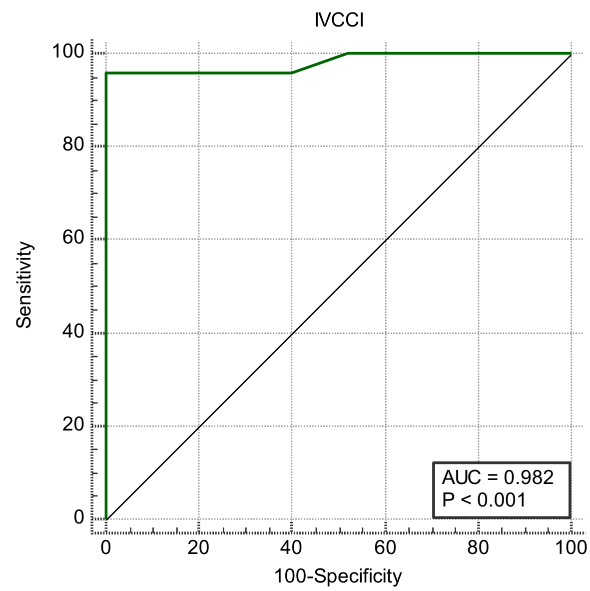

Fig. 2 ROC curve for IVCCI value to discriminate patients (*n* = 25) from control (*n* = 25)

Italian children and provided valid reference values for IVC diameters. In that study, the authors discovered that the reference value for the IVC collapsibility index was 30% for children older than one year and 36% for children less than one year.

A study by [14] evaluated 120 healthy American children with a mean age of 8.3 years. The IVC collapsibility index was 30 percent.

[9] demonstrated that an IVCCI of 0.22 predicted elevated CVP in spontaneously breathing pediatric cardiac patients with a sensitivity of 1.0 and specificity of 0.98.

Regarding [12], the receiver operator characteristic (ROC) curve analysis revealed that the IVCCI cutoff of 20% predicted CVP > 8 cmH2O with 91.1% sensitivity, 83.2% specificity, 71.8% positive predictive value, and 50.6% negative predictive value.

However, [15], published a review article containing 31 studies on IVC collapsibility, dispensability, and diameters. The study comprised three pediatric research, and the findings suggested that an ultrasonic evaluation of IVC diameters and respiratory fluctuations did not appear to be a valid tool for predicting fluid responsiveness. The disparity between research is attributable to differences in study populations and the primary state of the patient's fluid load.

In our study, we found that IVCCI can significantly discriminate patients from control group ($P < 0.001$), at cutoff ≤ 39.5 with 100.0% sensitivity and 96.0% specificity.

The difference between studies could be attributed to differences in participant age, showing that respirophasic variation (change in breathing pattern) of IVCD is substantially less in children than in adults. The effects of respiratory efforts on IVCCI may account for the difference in the cutoff between children in the current study and adults in the previous studies, because children have higher respiratory rates and shallower inspiration than adults, potentially resulting in smaller IVCCI in children than in adults. Second, as the relationship between venous pressure and volume is determined by venous compliance, changes in venous compliance across patients may impact the IVCCI-CVP relationship [9].

The mean IVC/AO ratio for controls in our study was (0.67 ± 0.12), lower than controls in [16] study (0.99 ± 0.06), and controls in [17] study (1.01 ± 0.15) (Table 2**,** Fig. 1).

Other studies by [18] and [19], the results were marginally higher at (1.2 ± 0.12) and (1.2 ± 0.17). Our study found a considerably greater IVC/AO ratio in patients (1.07 ± 0.25) compared to controls (0.67 ± 0.12), likely due to increased IVC levels in cardiac patients; studies show a link between the IVC/AO ratio and volume overload in our cardiac newborn patients In parallel with [18], A prospective cross-sectional descriptive study was done to determine the efficacy of the inferior vena cava and aorta (IVC/Aorta) index in measuring fluid status when compared to central venous pressure (CVP). According to the study, patients with euvolemia have a mean IVC/Ao of 1.2 ± 0.12, which is lower than the volume overloaded value of 1.6 ± 0.05.

On the other hand, [20] aimed to compare the ultrasound measured as (IVC/Ao) to other common methods to assess fluid status in mechanically ventilated pediatric critically ill patients including central venous pressure (CVP), percent fluid overload by weight (%FOw), and percent fluid overload by volume (%FOv), they found no significant correlation between IVC/Ao measurements and CVP or other markers of fluid overload, including %FOw and %FOv, and this difference contributed to that these patients were in mechanical ventilation. In the current study, IVC/AO was insignificantly different between the studied case groups (compensated and decompensated case groups). However, in compensated group there was slight increase in values than before compensation [21] and showed that systolic aortic diameter does not change before and after hydration and [22] reported that mean aortic abdominal diameter remained constant despite large blood losses. These data suggest the use of IVC/AO ratio, rather than the IVC diameter alone in some conditions.

In the present study, IVC/AO can significantly discriminate patients from control group ($P < 0.001$) with AUC of 0.937 (95% CI 0.856–0.986), at cutoff > 0.85 with 88.0% sensitivity and 100.0% specificity that shows high sensitivity and specificity indicating its value in fluid assessment (Table 4).

However, regarding our knowledge there were scarce data about this parameter among overloaded cases Regarding correlations, we found that IVC/AO value had a moderate significant negative correlation with IVCCI and a strong significant positive correlation with Inferior vena cava (IVC) diameter value ($r = 0.865$, $P < 0.001$). No correlation was reported with weight, height, or BMI (Table 5, Figs. 3, 4, 5).

Table 5 Correlation between Doppler parameters in all neonates ($n = 50$)

		IVC/AO	IVCCI
IVCCI	r_s value	−0.537	
	p value	< 0.001	
Inferior vena cava (IVC)	r_s value	0.865	−0.527
	p value	< 0.001	< 0.001
Aorta (AO)	r_s value	−0.183	0.178
	p value	0.204	0.217

IVC/AO value had a moderate significant negative correlation with IVCCI ($r = -0.537$, $P < 0.001$) and a strong significant positive correlation with inferior vena cava (IVC) diameter value ($r = 0.865$, $P < 0.001$)

IVCCI value had a moderate significant negative correlation with inferior vena cava (IVC) diameter value ($r = -0.527$, $P < 0.001$)

Table 4 Prognostic performance for different parameters to discriminate patients ($n = 25$) from control ($n = 25$)

	AUC	*P* value	95% CI		Cutoff point	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
			Lower	Upper					
IVC/AO	0.937	**< 0.001**	0.856	0.986	**> 0.84**	88.0	100.0	100.0	89.3
IVCCI	0.982	**< 0.001**	0.896	1.000	**≤ 0.38**	96.0	100.0	100.0	96.2

AUC: Area Under a Curve, *p* value: Probability value, CI: Confidence Intervals

*: Statistically significant at $p \leq 0.05$

IVC/AO can significantly discriminate patients from control group ($P < 0.001$) with AUC of 0.937 (95% CI 0.856–0.986), at cutoff > 0.85 with 88.0% sensitivity and 100.0% specificity

IVCCI can significantly discriminate patients from control group ($P < 0.001$) with AUC of 0.018 (95% CI 0.000–0.055), at cutoff ≤ 39.5 with 100.0% sensitivity and 96.0% specificity

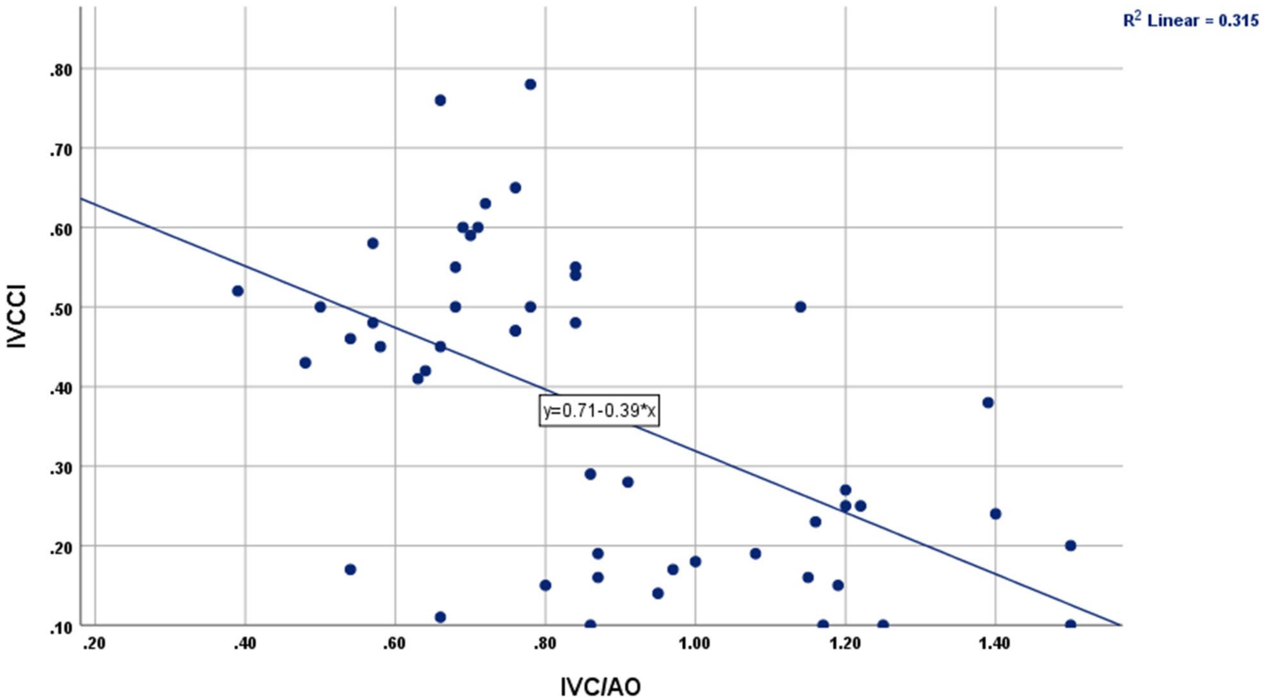

Fig. 3 Correlation between IVC/AO value and IVCCI in all neonates

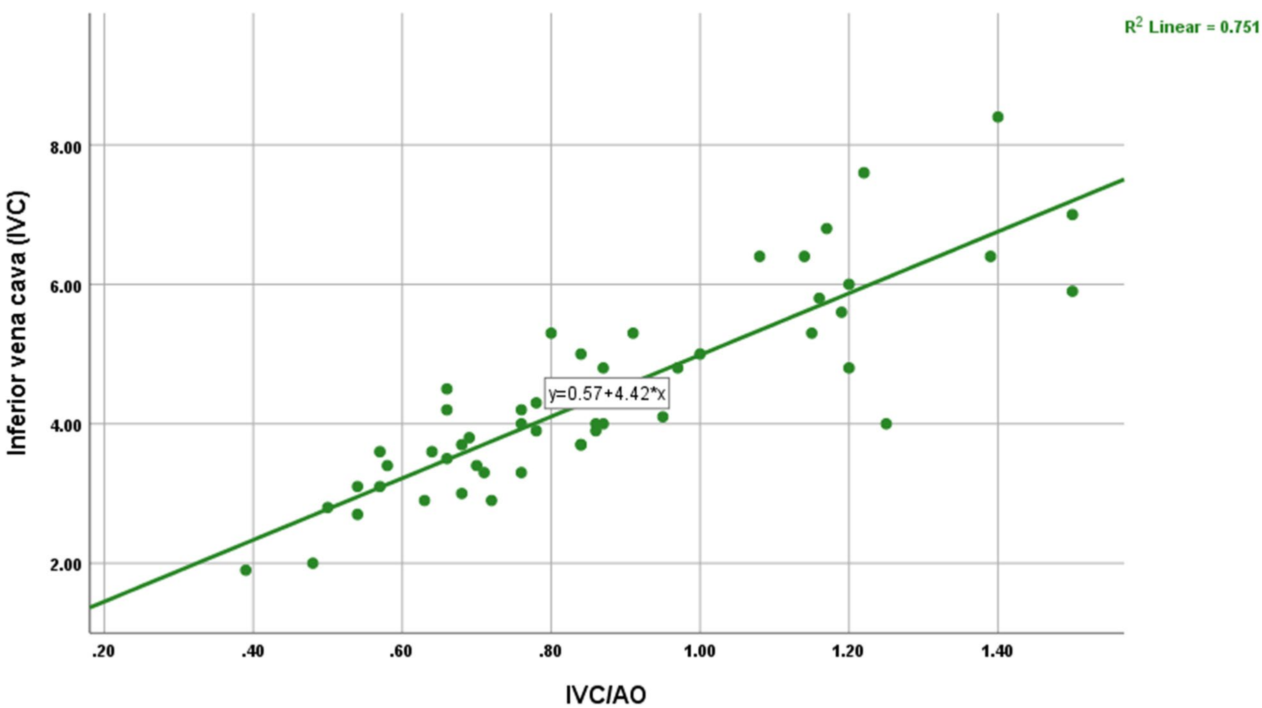

Fig. 4 Correlation between IVC/AO value and IVC diameter in all neonates

Utilizing the IVC/Ao ratio as an ultrasonic component to evaluate volume status is a relatively recent development. From a technical standpoint, the sonographic evaluation of the IVC/Ao diameter ratio is a simple test that may be successfully completed by physicians without special training in sonography (Fig. 6). The study by [23]

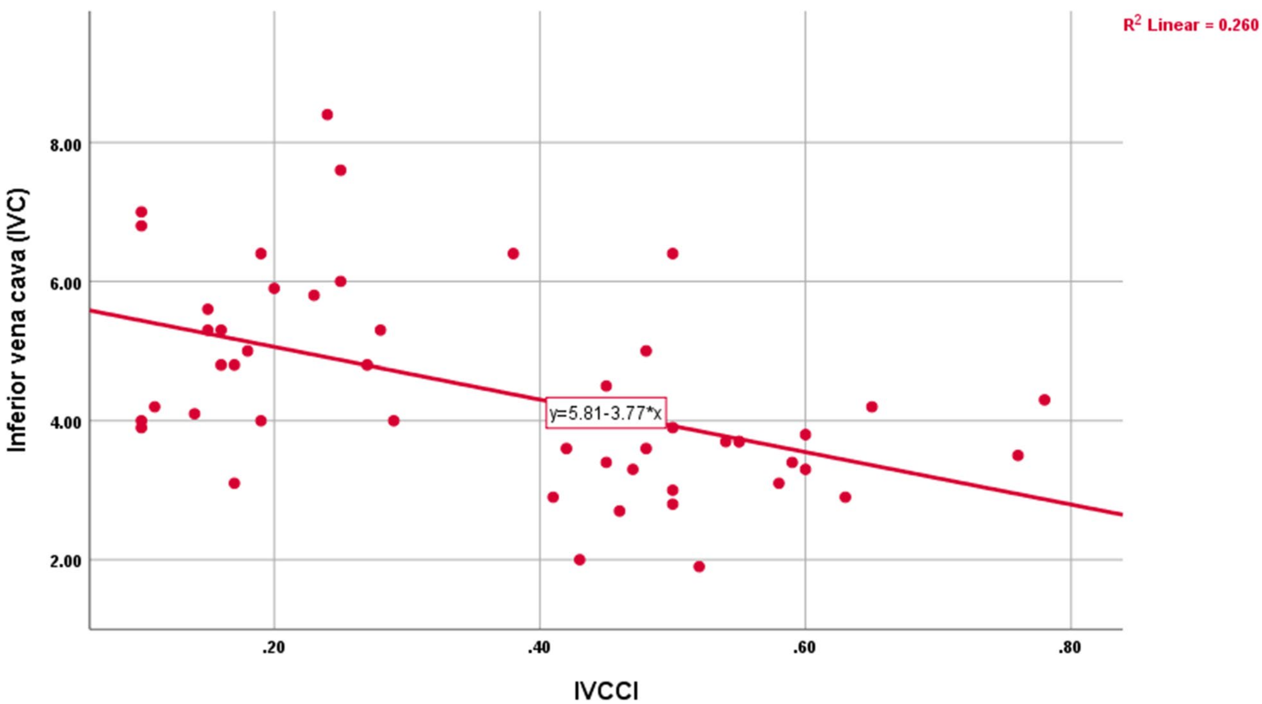

Fig. 5 Correlation between IVCCI value and IVC diameter in all neonates

Fig. 6 A 30-day-old full-term female neonate presented by tachycardia, tachypnea, and diminished feeding. Echo findings: TGA, pulmonary stenosis, VSD (7 mm), ASD II (LT to RT shunt), DOLV (dilated obstructed left ventricle). Abdominal ultrasound and M mode Doppler showed reduced IVCCI and elevated IVC/AO ratio

found that an ultrasound examination of the IVC and Ao diameters is not a complex examination and that, with 4 h of training, a person without any prior ultrasonography experience can perform an examination of the IVC and Ao diameters with an accuracy level comparable to experienced examiners. Our main limitation was the small sample size of studied patients and the lack of correlation with CVP parameters.

Conclusions

Fluid overload with increased IVC diameter and lack of IVC collapsibility were observed in neonates with congenital heart diseases and congestive heart failure compared with those hemodynamically stable controls. We recommend the use of IVC diameter, IVCCI and IVC/AO ratio as rapid, easy and sensitive parameters in assessing volume status.

Abbreviations

IVC	Inferior vena cava
IVC/AO	Inferior vena cava-to-aortic ratio
IVCCI	Inferior vena cava collapsibility index
TBW	Total body water
ECF	Extracellular fluid
ICF	Intracellular fluid
CVP	Central venous pressure
BMI	Body math index
VSD	Ventricular septal defect
ASD	Atrial septal defect
DOLV	Dilated obstructed left ventricle
FOw %	Percent fluid overload by weight
FOv %	Percent fluid overload by volume

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Author contributions
RHH and ROM reviewed the images. YAM and KMH analyzed and interpreted the patient data. ROM and RHH wrote the manuscript, and ROM, RHH, and YAM reviewed it. All authors have read and approved the manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Approval of the ethical committee of the 'Radiology department, Faculty of Medicine, Cairo University' was granted before conducting this prospective study; Reference number: not applicable. Local institutional review board approval was granted before conducting this cross-sectional study, and written informed consent was obtained from all patients.

Consent for publication
Verbal informed consent for the publication of these data was given by their parents or legal guardians.

Competing interests
All authors declare they have no financial interests.

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