Original Article

Correlation Between Biodemographic Parameters and the Size of Inferior Vena Cava and Collapsibility Index Using Ultrasound in Children

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ABSTRACT

Background and Aim: There is a concern regarding the relationship between biodemographic parameters at different ages and the size of inferior vena cava (IVC) and the collapsibility index (CI). Due to the lack of normative data on these parameters in children, we aimed to use ultrasound to determine the mean sizes of IVC in healthy children and calculate the CI.

Methods: In this analytical cross-sectional study, we measured the IVC diameter in euvolemic children aged four weeks to 12 years. The maximum IVC diameter was recorded during the exhalation phase of the respiratory cycle, while the minimum diameter was recorded during the inhalation phase using M-mode. Additionally, we calculated the CI by dividing the difference between the maximum and minimum IVC diameters by the maximum diameter.

Results: In this study, 534 euvolemic healthy children with a mean age of 6.77±3.22 years were assessed. The mean diameter of the maximum IVC during exhalation was 5.26±4.70 and the mean diameter of the minimum IVC during inspiration was 2.96±2.89 mm. The mean CI in the present study was 0.5±0.13. Ultrasound measurements of IVC diameter during exhalation, unlike IVC diameter during inhalation, were positively correlated with age, weight, and height. The mean IVC and CI had a direct and significant correlation with biodemographic parameters, such as age, height, weight, and body mass index.

Conclusion: Evaluating intravascular volume status holds significant clinical relevance, particularly in pediatric patients. Utilizing ultrasound to assess the IVC allows for swift and non-invasive analysis of an individual's hemodynamics, impacting clinical decision-making positively. Establishing normative IVC measurements in healthy and euvolemic children can serve as valuable reference data for clinicians and help them accurately assess fluid status in unwell pediatric patients.

Keywords: Inferior vena cava, Ultrasound, Cardiovascular diseases

Introduction

Assessing patients' hemodynamic status and making critical resuscitation decisions are challenges faced by healthcare providers. Understanding intravascular volume as a key determinant of hemodynamic status is crucial in critically ill patients [1]. However, conventional methods for measuring intravascular volume are often invasive, associated with potential risks and high costs, and may lead to delayed treatment [2]. Moreover, performing these invasive tests can be particularly challenging in pediatric patients who may not cooperate [3]. Therefore, the development of non-invasive techniques for intravascular volume measurement is imperative.

Ultrasonography is a non-invasive diagnostic tool widely utilized in pediatric emergency medicine [4-8]. It allows the assessment of the diameter of the vein and artery and helps to determine the volume of circulating fluid [9-10]. The inferior vena cava (IVC) as the largest vein is a complementary parameter to other intravascular volume estimators. During inhalation, the diaphragm descends, expanding the chest cavity and increasing intra-abdominal pressure, causing the IVC walls to contract, reducing its diameter [11]. Conversely, during exhalation, as the diaphragm relaxes and abdominal pressure drops, the IVC diameter returns to its original size [12]. In subjects with regular breathing patterns and good health, these cyclic changes in pleural pressure led to fluctuations in IVC diameter. Monitoring these respiratory-induced fluctuations in IVC diameter can guide assessments of a patient's volume status [13]. The collapsibility index (CI), calculated by measuring the difference between the maximum and minimum IVC diameters and dividing it by the maximum diameter is another parameter used to evaluate the volume status of patients with stable hemodynamics [14, 15].

There is a concern about the relationship between biodemographic parameters at different ages and IVC size. Previous studies have suggested correlations between IVC size (IVCmax and IVCmin) and factors, such as age, height, weight, body surface area (BSA), and CI [16-18]. Given the lack of normative data for these parameters in children, we employed ultrasound to determine the mean IVC sizes during both inhalation and exhalation in healthy children. We also calculated the CI and investigated how these measurements correlate with biodemographic parameters. We believe that conducting these investigations enables clinicians to establish age-specific cut-off points for this age group.

Materials and Methods

In this analytical cross-sectional study, we examined children aged four weeks to 12 years who were referred to 17 Shahrivar Hospital in Rasht, and visited the outpatient clinic between July 2022 and April 2023. We employed a convenient sampling method for participant selection. Exclusion criteria included children with abnormal vital signs, shortness of breath, fever, congenital heart disease, intestinal obstruction, any signs of increased abdominal pressure, or any medical condition that could potentially affect intravascular volume.

Sample size

To determine the sample size, we classified participants based on age and considered changes in IVCmin within each age category. Accordingly, with standard deviations of 0.97 (for those under one year), 1.18 (for those aged 1-3 years), 1.17 (for those aged 3-6 years), 1.42 (for those aged 6-9 years), and 1.86 (for those aged 9-12 years), and a significance level of 0.05, the minimum required sample sizes for these respective age categories were 91, 86, 85, 124, and 148, respectively. Consequently, the total sample size was considered 534 participants as below (Equation 1):

1.

$$n_{<1}=\frac{\left(z_{1-\frac{\alpha}{2}}\right)^2.\sigma^2}{d^2}=\frac{(1.96)^2\times 0.97^2}{(0.2)^2}=90.36\cong 91$$

$$n_{1-3}=\frac{\left(z_{1-\frac{\alpha}{2}}\right)^2.\sigma^2}{d^2}=\frac{(1.96)^2\times 1.18^2}{(0.25)^2}=85.58\cong 86$$

$$n_{3-6}=\frac{\left(z_{1-\frac{\alpha}{2}}\right)^2.\sigma^2}{d^2}=\frac{(1.96)^2\times 1.17^2}{(0.25)^2}=84.14\cong 85$$

$$n_{6-9}=\frac{\left(z_{1-\frac{\alpha}{2}}\right)^2.\sigma^2}{d^2}=\frac{(1.96)^2\times 1.42^2}{(0.25)^2}=123.94\cong 124$$

$$n_{9-12}=\frac{\left(z_{1-\frac{\alpha}{2}}\right)^2.\sigma^2}{d^2}=\frac{(1.96)^2\times 1.86^2}{(0.3)^2}=147.67\cong 148$$

During the examination, we documented weight and height measurements for the participants. We employed a baby scale to weigh infants, while older children's weight was determined using a digital scale with a precision of 10 g. For children under two years old, we measured their length while lying down using a baby height meter, whereas children over two years of age had their height measured with a stadiometer, which provided measurements accurate to 1 mm. Subsequently, we used the DuBois & DuBois formula to calculate their body surface area (BSA) based on their weight and height.

A cardiologist utilized a Philips S50 echocardiography machine to gauge the diameter of the IVC. The procedure involved placing the children in a supine position and positioning the transducer longitudinally on the subxiphoid area. Precise measurements of the IVC diameter were taken near its entrance into the right atrium, approximately 1 to 3 cm from the right atrium. These measurements were obtained using M-mode imaging during both the exhalation and inspiration phases of the respiratory cycle. To further assess the cardiovascular condition, we computed the CI by dividing the difference between the maximum (exhalation) and minimum (inspiration) diameters of the IVC by the maximum IVC diameter.

IVC_{CI}: Maximum diameter of the IVC–minimum diameter of the IVC/maximum diameter of the IVC

In this research, we applied various statistical methods tailored to the nature of the data under investigation. For qualitative data, descriptive statistics, such as frequency and percentage. Conversely, for quantitative data, we utilized measures, like the Mean±SD to summarize central tendencies and dispersion.

To assess the normal distribution of the quantitative data, we conducted the Shapiro-Wilk test. When the relevant assumptions were met, we performed analytical tests, such as the independent t-test and Pearson correlation coefficient. In cases where the assumptions were not met, we used the Mann-Whitney U test and Spearman correlation coefficient. We employed linear regression for variables that could affect the results. Data analysis was carried out using SPSS software, version 24. A $P<0.05$ indicated statistical significance.

Results

We enrolled a total of 534 typically developing children. The largest proportion (32.8%) of participants fell within the age group of 6-9 years, accounting for 175 cases. The mean age of the children was 6.77±3.22 years. Also, 297(55.6%) were boys, while 237 cases (44.4%) were girls. On average, the children weighted 25 kg, a height of 1.19 m, and a body mass index (BMI) of 16.7 kg/m². In terms of vascular measurements, the mean minimum and maximum diameters of the IVC were 2.96±2.89 and 5.26±4.70 mm, respectively. The mean CI was 0.5±0.13.

The ANOVA results indicated significant differences in the mean IVC diameter during inspiration and the mean CI across various age groups (P=0.048 and 0.001, respectively). Notably, the age group under three years old stood out as distinct from the other age groups in terms of both mean IVC diameter during inspiration and mean CI (Table 1). However, there was no significant difference in mean IVC diameter during exhalation among different age groups (P=0.061). Furthermore, we conducted the independent sample t-test to investigate potential differences in mean measurements between genders. The results revealed no significant disparities between male and female participants in terms of mean IVC diameter during inspiration (P=0.115), mean IVC diameter during exhalation P=0.126), or mean CI (P=0.297) (Table 1).

Our analysis using Spearman's correlation coefficient revealed no significant correlation between IVC diameter during inspiration and biodemographic parameters, as none of the $P<0.05$.

Conversely, we observed a significant correlation between IVC diameter during exhalation and certain biodemographic factors. Specifically, age (P=0.004, r=0.12), height (P=0.006, r=0.12), and weight (P=0.035, r=0.09) demonstrated significant associations. Intriguingly, all somatic factors exhibited meaningful correlations with the CI. These associations were consistently positive, with correlation coefficients ranging from 0.11 to 0.16. This indicates that an increase in age, height, weight, and BMI corresponded to an increase in the CI, as presented in Table 2.

We conducted a linear regression analysis to examine the combined influence of age, sex, and biodemographic factors on IVC diameter during both inspiration and exhalation, as well as on the CI. Surprisingly, the outcomes revealed that none of these variables emerged as predictors for the evaluated parameters, as demonstrated in Table 3.

Discussion

In the management of critically ill patients, assessing intravascular volume status is a crucial aspect of effective fluid therapy. Handling fluid therapy in pediatric patients demands a high level of sensitivity due to the need for precise evaluation of dehydration or fluid overload. Conventional methods, like central venous pressure (CVP) measurement, have limitations and can be invasive. As a result, bedside ultrasound has emerged as a non-invasive and easily accessible tool for evaluating intravascular volume status [19]. While echocardiography can also assess fluid balance, it presents greater challenges compared to ultrasound examinations. Therefore, the use of ultrasound for assessing volume status in children is a suitable choice due to its non-invasive and accessible nature. However, data on the normal range of IVC diameter in healthy children is comparatively scarce, unlike the well-established range for adults, which typically falls between 1.7 and 2.1 cm^2. Previous studies have examined respiratory changes in IVC diameter among patients during spontaneous breathing and mechanical ventilation [16-21]. However, there is a significant lack of normative data on IVC diameter for healthy children.

Table 1. The IVC and CI values based on age and sex

Ultrasonographic Findings	Characteristics		Mean±SD	P
Mean IVC diameter during inspiration	Sex	Male	3.09±2.98	0.115
		Female	2.79±2.78	
	Age (y)	<3	2.34±1.42	0.048
		3-6	3.17±2.19	
		6-9	2.71±2.64	
		9-12	3.33±3.84	
Mean IVC diameter during exhalation	Sex	Male	5.47±4.85	0.126
		Female	5±4.49	
	Age (y)	<3	4.30±2.50	0.061
		3-6	5.46±3.20	
		6-9	4.90±4.37	
		9-12	5.91±6.28	
Mean CI	Sex	Male	0.49±0.13	0.297
		Female	0.5±0.13	
	Age (y)	<3	0.48±0.11	0.001
		3-6	0.46±0.14	
		6-9	0.51±0.13	
		9-12	0.52±0.12	

We enrolled 534 healthy children with normal intravascular volume, averaging 22.3±7.6 years of age. Utilizing a convenient sampling method, we categorized the participants into four distinct age groups, each containing a minimum of 70 individuals. We determined that the mean maximum IVC diameter during inspiration was 5.26±4.7 mm, while the mean minimum IVC diameter during exhalation was 2.96±2.98 mm. Despite the significant variations in body proportions and growth rates between boys and girls, our study did not detect any significant differences in IVC diameter between the two genders.

Our findings unveiled a direct and significant correlation between age and maximum IVC diameter, which shows that with increasing age, the maximum diameter of the IVC also increases. Similarly, the age group under three years exhibited a significantly lower mean IVC diameter during exhalation compared to the age groups of 3-6 years and 9-12 years. This age-related trend in maximum IVC diameter aligns with observations in studies conducted on children in Western countries [22, 23]. Additionally, Zaoral et al. [18] examined IVC diameter in 400 healthy children with a mean age of 5.8±7.8 years and revealed a positive correlation between both IVCmax and IVCmin diameters and age. This is consistent with our study and in agreement with findings from studies by Kutty et al. [23] and Ayvazyan et al. [24]. Nevertheless, Masugata et al. [21] assessed an adult population and showed a significant negative correlation between age and IVCmax diameter. These varying results could be attributed to other age-related factors, like arterial stiffness, high blood pressure, type 2 diabetes, and dyslipidemia, as well as the Western setting and presence of cardiovascular risk factors in other studies.

We also identified a significant positive correlation between height, weight, and IVC diameter during inspiration. As both height and weight increased, the IVC diameter during inspiration also increased. Similar posi-

Table 2. The correlation between biodemographic parameters and a IVC and CI

Biodemographic Parameters		r	P
IVC diameter during inspiration	Age (y)	0.08	0.051
	Height (m)	0.08	0.051
	Weight (kg)	0.05	0.221
	Body mass index (kg/m²)	- 0.03	0.431
IVC diameter during exhalation	Age (y)	0.12	0.004
	Height (m)	0.12	0.006
	Weight (kg)	0.09	0.035
	Body mass index (kg/m²)	-0.01	0.760
CI	Age (y)	0.13	0.002
	Height (m)	0.13	0.002
	Weight (kg)	0.16	<0.001
	Body mass index (kg/m²)	0.11	0.011

Table 3. The regression analysis of biodemographic parameters and IVC and CI

Ultrasonographic Findings	Biodemographic Parameters	B	SD	Beta	P
IVC diameter during exhalation	Age (y)	0.08	0.15	0.05	0.558
	Sex	-0.44	0.40	-0.04	0.281
	Height (m)	-0.93	3.19	-0.04	0.771
	Weight (kg)	0.06	0.05	0.17	0.280
	Body mass index (kg/m²)	-0.16	0.09	-0.14	0.101
IVC diameter during inspiration	Age (y)	0.03	0.09	0.03	0.713
	Sex	-0.28	0.25	-0.04	0.258
	Height (m)	-0.26	-1.96	-0.02	0.892
	Weight (kg)	0.03	0.03	0.15	0.340
	Body mass index (kg/m²)	-0.09	0.06	-0.13	0.131
CI	Age (y)	0.004	0.004	0.09	0.357
	Sex	0.008	0.01	0.03	0.467
	Height (m)	0.05	0.08	0.09	0.541
	Weight (kg)	-0.001	0.002	-0.10	0.494
	Body mass index (kg/m²)	0.004	0.003	0.14	0.097

SD: Standard deviation.

tive correlations with age, weight, height, and BMI in children were reported in a study conducted in India. Zaoral et al. also found positive correlations between IVCmax and IVCmin diameters and age, weight, height, and BMI [18]. Kutty et al. discovered a positive correlation between body surface area (BSA) and IVCmax diameter [23]. In summary, our study suggests that as children grow (with increasing age, height, weight, and BSA), both IVCmax and IVCmin diameters tend to increase. However, in our study, no significant correlation was observed between IVC diameter during exhalation and biodemographic parameters.

We also measured the CI of the IVC as an indicator of fluid responsiveness. It was calculated by dividing the difference between the IVCmax and IVCmin diameters by the maximum diameter. Typically, the normal range of CI in adults falls between 0.35 and 0.50, with an optimal value of 0.40. Values above 0.55 and below 0.35 are considered abnormal [25]. In our study, the CI was determined to be 0.13±0.05.

Our findings indicated a significant statistical relationship between the CI and age, height, and weight. However, none of the independent variables, such as age, gender, height, weight, and BMI, demonstrated a significant effect on the CI, as determined by linear regression analysis. This contradicts the results of other studies that found no significant correlation between the CI and biodemographic parameters. Instead, these studies highlighted a dependency on the fluid status of individuals [26-30].

The discrepancy in results between our study and others may be attributed to racial differences, variations in sample sizes, and differences in age distributions among the children studied. Furthermore, recent studies have suggested that the CI of the subdiaphragmatic IVC is significantly associated with CVP [31, 32]. However, Özkan et al. in their study on 124 children aged eight months to 17 years, found no significant change in the CI of the subdiaphragmatic IVC after fluid therapy [33].

Additionally, regular assessment of the CI should be considered within different clinical contexts. The dynamic assessment of changes in the CI at the outset and during treatment may provide insights into its relationship with intravascular volume and assist in making informed decisions regarding appropriate fluid therapy. Furthermore, it is worth noting that the variability of the CI may depend not only on the speed and volume of respiration but also on the respiratory pattern [34]. Infants and children rely more on their abdominal muscles for respiration compared to adults, which may explain the greater variability of the CI in younger age groups. However, this aspect requires further investigation and confirmation in future studies.

Conclusion

In conclusion, evaluating intravascular volume holds significant importance, especially in pediatric patients. Ultrasonographic measurement of IVC offers a swift and non-invasive approach to gaining insights into an individual's hemodynamics, which can greatly influence clinical decision-making. Our study unveiled a positive association between IVC diameter during inspiration and age, weight, and height, while the CI displayed a direct and significant association with biodemographic factors, such as age, height, weight, and BMI.

The availability of data on IVC measurements in healthy euvolemic children can provide valuable assistance to healthcare professionals in assessing fluid status in sick children. Nevertheless, it is crucial to notice various limitations and consider diverse clinical contexts when determining appropriate treatment strategies in the realm of pediatric care; these IVC sonographic indices offer a valuable non-invasive guide for evaluating intravascular volume status.

Ethical Considerations

Compliance with ethical guidelines

Ethical considerations

Written informed consent was obtained from all patients or parents/guardians. This study was ethically approved by the ethics committee of the Vice-Chancellor of Research at Guilan University of Medical Sciences (Code: IR.GUMS.REC.1401.151).

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Authors' contributions

All authors equally contributed to the preparation of this article.

Conflict of interest

The authors declared no conflict of interest.

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