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Original Article

Correlation between ultrasound-measured inferior vena cava diameter and peripherally inserted central catheter measured central venous pressure in low birth weight infants

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Abstract: Objective: To evaluate the correlation between ultrasound-measured inferior vena cava (IVC) diameter and central venous pressure (CVP) measured by peripherally inserted central catheter (PICC) in low birth weight infants (LBWI) and explore potential influencing factors. Methods: This retrospective study included 120 LBWI with birth weights below 2500 g who required umbilical vein catheterization at Huadu District People's Hospital of Guangzhou from May 2022 to April 2024. Infants were categorized based on PICC catheterization into two groups. Clinical data, including ultrasound-measured IVC small diameter (SD) and large diameter (LD) at the level of the left portal vein, were collected. The SD/LD ratio (S/L) was calculated, and logistic regression analyses (univariate and multivariate) were performed to identify factors influencing PICC catheterization. Correlations between SD, LD, S/L, and CVP were analyzed. Results: Multivariate logistic regression identified gestational age, birth weight, SD, S/L, and CVP as significant factors influencing PICC catheterization in LBWI (all $P < 0.05$). SD and S/L showed a positive correlation with CVP (both $P < 0.05$). The S/L ratio was significantly correlated with gestational age, birth weight, ventilator mode, tricuspid regurgitation, and vasoactive drug use (all $P < 0.05$). Conclusion: Birth weight, SD, S/L ratio, and CVP are significant factors affecting PICC placement in LBWI. There is a notable correlation between ultrasound-measured IVC SD and S/L ratio and PICC-measured CVP in LBWIs.

Keywords: Vena cava, central venous pressure, ultrasound, central venous catheter, low birth weight infants, umbilical vein

Introduction

Low birth weight infants (LBWI) are defined as newborns with a birth weight under 2500 g, with a global incidence rate of approximately 15.5% [1]. With the implementation of China's three-child policy, the number of elderly pregnancies and high-risk cases have risen, leading to an increased proportion of premature and LBWI births. Concurrently, advancements in neonatal intensive care and perinatal medicine have significantly improved the survival rates of premature infants and LBWI [2, 3]. LBWI are a major concern in neonatal care, as they are associated with higher morbidity and mortality and are risk factors for chronic conditions in adulthood, such as hypertension, diabetes, obesity, and cardiovascular and cerebrovascular disease [4, 5].

The peripherally inserted central catheter (PICC) is commonly used for central venous pressure (CVP) measurement in neonates, serving as a critical indicator of right atrial pressure and systemic blood volume. CVP measurement is essential for guiding fluid resuscitation, assessing cardiac function, and evaluating hemodynamic status [6, 7]. Numerous studies have confirmed the accuracy and consistency between CVP measurements obtained by PICC and central venous catheter (CVC) [8, 9]. However, measuring CVP through PICC is invasive and subject to factors like catheter positioning, patient posture, and respiratory movement, all

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of which can result in PICC mispositioning. PICC mispositioning may increase the risk of complications, including phlebitis, thrombosis, and arrhythmias, thereby complicating treatment, prolonging hospital stays, and adding to the financial burden on families [10, 11]. This challenge has drawn scholarly interest in strategies to prevent PICC mispositioning in LBWI.

Ultrasound technology has gained prominence in clinical settings, especially in neonatal and critical care. As a non-invasive tool, ultrasound measurement of the inferior vena cava (IVC) diameter is increasingly recognized for evaluating blood volume and fluid responsiveness due to its convenience, repeatability, and accuracy [12]. The IVC, the largest vein in the low-pressure venous system, reflects venous pressure and vascular content through changes in diameter [13]. Thus, IVC diameter is considered a candidate diagnostic marker for assessing blood volume status [14].

Previous research has identified a correlation between IVC diameter and CVP in adults [11, 15, 16] and children [17], indicating its utility in assessing right cardiac preload and fluid status. Some clinical studies have further explored ultrasound measurements of IVC variation parameters or collapse index to estimate CVP in neonates, yielding promising results [17, 18]. However, there is limited clinical data specifically addressing the correlation between ultrasound-measured IVC diameter and PICC-measured CVP in LBWI. This study aims to explore this correlation and evaluate the clinical value of IVC diameter as a non-invasive indicator for CVP in LBWI.

Materials and methods

Participant information

This retrospective study included 120 cases of LBWI with birth weights below 2500 g who required umbilical vein catheterization and were admitted to Huadu District People's Hospital of Guangzhou from May 2022 to April 2024.

Inclusion criteria: (1) Birth weight < 2500 g; (2) Hospital stay of more than 7 days, including both preterm (gestational age < 37 weeks) and full-term infants (gestational age 37-42 weeks); (3) No contraindications for CVP or vena cava measurements; (4) Required umbilical vein catheterization.

Exclusion criteria: (1) Infants with birth weight < 1500 g; (2) Presence of congenital genetic metabolic diseases, congenital infections, severe congenital malformations, or neurodevelopmental disorders; (3) Cases requiring surgical treatments during the neonatal period or deaths during the study period. This study was approved by the Ethics Committee of Huadu District People's Hospital of Guangzhou (**Figure 1**).

Methods

(1) PICC catheterization: PICC catheterization was performed by nurses certified in PICC procedures. The major vein at the elbow was chosen following an assessment of catheterization indications and contraindications. The infant was placed in the supine position with the arm abducted at 90°. The vein was measured from the puncture point to the sternoclavicular joint to determine catheter length. After sterilization, venipuncture was conducted, and the catheter was advanced to the required length, flushed with heparin solution, and secured with dressing. Fluoroscopy confirmed that the catheter tip was positioned at the junction of the superior vena cava and right atrium. (2) CVP measurement: To ensure measurement accuracy, CVP measurements were performed by nurses trained in standardized CVP measurement techniques. Using a multi-functional monitor (IntelliVue MP5, Philipis, Germany), central venous pressure, heart rate, blood oxygen saturation (SpO2), and mean arterial pressure (MAP) were recorded. The closed pressure sensor method was used, with measurements taken in the supine position three times per day at 08:00, 16:00, and 24:00, at 8-hour intervals. The average value was calculated. (3) Ultrasonic measurement: Ultrasound measurements were performed using a ultrasonic diagnostic instrument (Vivid™ iq, GE, China) by a skilled cardiac sonographer. The IVC diameters, small diameter (SD) and large diameter (LD), were measured on the subcostal transverse plane (short axis) at the level of the left portal vein. Measurements were conducted three times daily at 08:00, 16:00, and 24:00, and the average values were recorded.

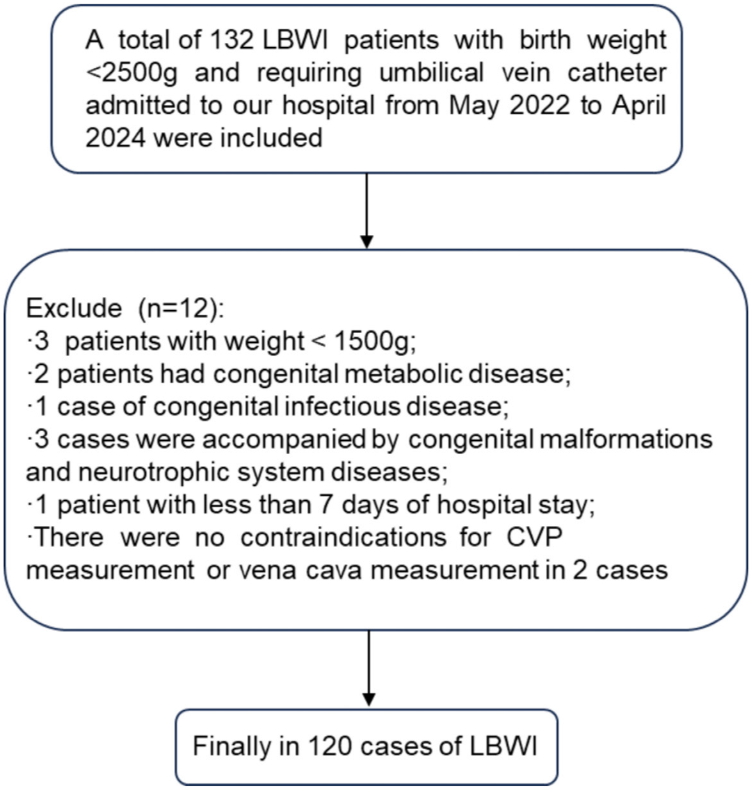

Figure 1. Flowchart. CVP, central venous pressure; LBWI, low birth weight infant.

Clinical data

Clinical data were collected on factors affecting hemodynamics, including prenatal factors (e.g., prenatal hormone use, maternal hypertension), gestational age, birth weight, systolic and diastolic blood pressure, mean arterial pressure (MAP1), ventilator mode, positive end-expiratory pressure (PEEP), mean airway pressure (MAP2), complications (mild pulmonary hypertension, mild tricuspid regurgitation), and vasoactive drug use.

Criteria for PICC ectopic placement

Based on LBWI PICC X-ray examination, catheter tip positioning within the superior vena cava was considered optimal. Catheter tips positioned in the internal jugular, axillary, subclavian, or other veins were classified as ectopic placements [19, 20].

Evaluation criteria

CVP measured via PICC served as the reference standard, while ultrasound-measured IVC SD, LD, and the ratio of small-to-large diameter (S/L) were used as observation indicators.

Primary outcomes

We analyzed the correlation between LD, SD, S/L, and CVP, as well as between SD, LD, S/L, and clinical data.

Secondary outcomes

Subjects were categorized based on PICC catheterization occurrence into the "occurrence" and "non-occurrence" groups. Univariate and multivariate logistic regression analyses were used to investigate factors influencing PICC ectopic placement.

Statistical analysis

Data were processed using SPSS version 29.0. Measured data confirmed to follow a normal distribution by K-S test were expressed as mean ± standard deviation (mean ± sd) Categorical variables were described as counts and percentages [n (%)]. Group comparisons were conducted using t-tests for continuous data and χ^2 tests for categorical data. Pearson correlation analysis was performed to assess correlations, with $P < 0.05$ considered significant.

Results

Basic information of children

In this study, 132 LBWI patients were initially reviewed. Of these, 12 patients were excluded based on the following criteria: 3 had birth weights under 1500 g, 2 had congenital metabolic diseases, 1 had a congenital infectious disease, 3 had congenital malformations or neurodevelopmental disorders, 1 was hospitalized for less than 7 days, and 2 had contraindications for CVP or vena cava measurements. Ultimately, 120 LBWI cases met the inclusion criteria (as shown in **Figure 1**). All included infants received ventilator-assisted ventilation.

Table 1. Clinical data of children

Item	Number of cases	Proportion (%)
Sex		
Male	57	47.50
Female	63	52.50
Gestational age (weeks)		
< 37	54	45.00
37-42	66	55.00
Birth weight (g)		
1500-1999	52	43.30
2000-2499	68	56.70
Prenatal hormone use		
Yes	52	43.30
No	68	56.70
Maternal hypertension		
Yes	51	42.50
No	69	57.50
Ventilator mode		
Invasive	52	43.30
Non-invasive	68	56.70
Pulmonary hypertension		
Yes	27	22.50
No	93	77.50
Tricuspid regurgitation		
Yes	90	75.00
No	30	25.00
SD (mm)	2.23±0.38	-
LD (mm)	3.99±0.46	-
S/L	0.57±0.13	-
Heart rate (times/min)	140.15±11.09	-
Systolic blood pressure (mmHg)	53.55±8.37	-
Diastolic blood pressure (mmHg)	29.55±6.74	-
MAP_1 (mmHg)	37.60±7.80	-
PEEP (cmH_2O)	5.30±0.68	-
MAP_2 (cmH_2O)	7.95±1.45	-
CVP (cmH_2O)	3.68±0.78	-

Note: SD, small diameter; LD, large diameter; S/L, small diameter/large diameter; MAP1, mean arterial pressure; PEEP, positive end expiratory pressure; MAP2, mean airway pressure; CVP, central venous pressure.

Table 2. Assignment situation

Factor	Variable	Assignment
Gestational age	X1	< 37 = 1, 37-42 = 0
Birth weight	X2	1500-1999 = 1, 2000-2499 = 0
SD	X3	Original value entry
S/L	X4	Original value entry
CVP	X5	Original value entry

Note: SD, small diameter; LD, large diameter; S/L, small diameter/large diameter.

The basic clinical characteristics are provided in **Table 1**.

Univariate and multivariate logistic analysis of PICC ectopic placement in LBWI

Among the 120 LBWI cases, 44 were identified with ectopic PICC placement, resulting in a 36.67% ectopic rate. Univariate analysis showed that gestational age, birth weight, ventilator mode, LD, SD, S/L, and CVP were associated with PICC ectopic placement (all $P < 0.05$). In this analysis, ectopic PICC placement (0 = no, 1 = yes) was set as the dependent variable, while variables with $P < 0.05$ in the univariate analysis were used as independent variables (assignment details are in **Table 2**). Multivariate logistic regression revealed that gestational age, birth weight, SD, S/L, and CVP were significant factors influencing PICC placement in LBWI (all $P < 0.05$). Refer to **Table 3**.

Correlation analysis of ultrasound-measured IVC SD, LD, S/L, and CVP

The correlation analysis revealed no significant correlation between LD and CVP ($r = 0.020$, $P = 0.828$). However, SD was positively correlated with CVP ($r = 0.821$, $P < 0.001$), and S/L also showed a positive correlation with CVP ($r = 0.705$, $P < 0.001$). See **Figure 2**.

Comparison of IVC S/L and CVP values under different clinical conditions

Significant differences in S/L values were observed based on gestational age, low birth

Table 3. Analysis of influencing factors for ectopic PICC catheterization in low birth weight infants

Factor	Single factor analysis		Multifactor analysis	
	HR (95% CI)	P	HR (95% CI)	P
Sex	1.564 (0.741-3.300)	0.241	-	-
Gestational age (weeks)	0.420 (0.193-0.914)	0.029	0.522 (0.183-0.483)	0.223
Birth weight (g)	3.792 (1.735-8.286)	< 0.001	3.755 (1.560-9.039)	0.003
Prenatal hormone use	0.855 (0.403-1.814)	0.684	-	-
Maternal hypertension	1.621 (0.765-3.433)	0.207	-	-
Ventilator mode	0.360 (0.167-0.774)	0.009	0.786 (0.253-2.438)	0.677
Mild pulmonary hypertension	0.829 (0.336-2.045)	0.683	-	-
Mild tricuspid regurgitation	0.475 (0.205-1.103)	0.083	-	-
Vasoactive drug	0.458 (0.202-1.041)	0.062	-	-
Heart rate (times/min)	1.002 (0.959-1.048)	0.913	-	-
Systolic blood pressure (mmHg)	1.008 (0.954-1.065)	0.702	-	-
Diastolic blood pressure (mmHg)	1.033 (0.984-1.084)	0.195	-	-
MAP_1 (mmHg)	1.064 (0.616-1.840)	0.823	-	-
PEEP (cmH_2O)	1.056 (0.817-1.366)	0.676	-	-
MAP_2 (cmH_2O)	0.744 (0.282-1.959)	0.549	-	-
LD	4.709 (1.861-11.915)	0.001	9.888 (2.090-46.779)	0.004
S/L	0.036 (0.002-0.827)	0.038	522.11 (1.430-190.680)	0.038
CVP	0.580 (0.348-0.967)	0.037	0.441 (0.221-0.881)	0.020

Note: SD, small diameter; LD, large diameter; S/L, small diameter/large diameter; MAP1, mean arterial pressure; PEEP, positive end expiratory pressure; MAP2, mean airway pressure; CVP, central venous pressure.

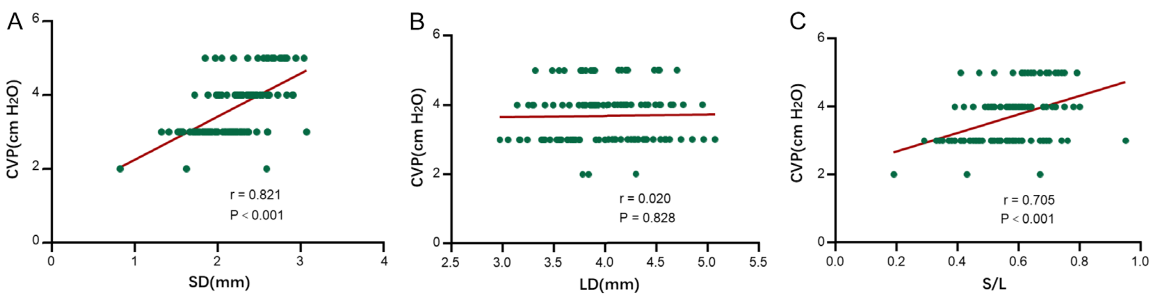

Figure 2. Scatter plot of correlation between SD, LD, S/L, and CVP. A. The relationship between SD and CVP; B. The relationship between LD and CVP; C. The relationship between S/L and CVP. SD, small diameter; LD, large diameter; S/L, small diameter/large diameter.

weight, ventilator mode, tricuspid valve regurgitation, and vasoactive drug use (all P < 0.05). No significant differences in S/L values were found based on gender, prenatal factors (e.g., prenatal hormone use, maternal hypertension), or mild pulmonary hypertension (all P > 0.05). Regarding clinical factors influencing CVP, no significant differences were observed in CVP measurements across groups for gender, gestational age, birth weight, prenatal hormone use, maternal hypertension, ventilator mode, pulmonary hypertension, mild tricuspid regurgitation, or vasoactive drug use (all P > 0.05) (**Table 4**).

Correlation of ultrasound-measured IVC S/L ratio and CVP with clinical factors

The S/L ratio was significantly correlated with gestational age, birth weight, ventilator mode, tricuspid valve regurgitation, and vasoactive drug use (all P < 0.05). No significant correlation was observed with sex, prenatal hormone use, maternal hypertension, mild pulmonary hypertension, heart rate, systolic blood pressure, diastolic blood pressure, MAP1, PEEP, or MAP2 (all P > 0.05). Additionally, CVP levels showed no significant correlation with sex, gestational age, birth weight, prenatal hormone

Table 4. Difference in IVC S/L results measured by ultrasound and CVP values measured by PICC under different clinical factors

Factor	Number of cases	Ultrasonic measurement of S/L			PICC measurement of CVP		
		$\bar{x}\pm s$	t	P	$\bar{x}\pm s$	t	P
Sex			0.860	0.392		0.579	0.564
Male	57	0.56±0.10			3.63±0.72		
Female	63	0.57±0.12			3.71±0.83		
Gestational age (weeks)			-3.140	0.002		1.048	0.297
< 37	54	0.60±0.12			3.59±0.79		
37-42	66	0.54±0.09			3.74±0.77		
Birth weight (g)			2.447	0.016		0.731	0.466
1500-1999	52	0.54±0.10			3.62±0.82		
2000-2499	68	0.59±0.11			3.72±0.75		
Prenatal hormone use			0.979	0.330		1.448	0.150
Yes	52	0.55±0.10			3.56±0.64		
No	68	0.57±0.12			3.76±0.87		
Maternal hypertension			0.718	0.474		-0.136	0.892
Yes	51	0.56±0.10			3.69±0.74		
No	69	0.57±0.12			3.67±0.82		
Ventilator mode			-4.109	< 0.001		-1.207	0.230
Invasive	68	0.60±0.10			3.75±0.78		
Non-invasive	52	0.52±0.11			3.58±0.78		
Pulmonary hypertension			1.724	0.087		1.472	0.144
Yes	27	0.53±0.12			3.48±0.75		
No	93	0.57±0.11			3.73±0.78		
Tricuspid regurgitation			-2.538	0.012		-1.714	0.091
Yes	90	0.58±0.11			3.74±0.80		
No	30	0.52±0.09			3.47±0.68		
Vasoactive drug			-3.737	< 0.001		-1.971	0.051
Yes	43	0.61±0.10			3.57±0.79		
No	77	0.54±0.11			3.86±0.74		

Note: S/L, small diameter/large diameter; CVP, central venous pressure; PICC, peripherally inserted central catheter.

use, maternal hypertension, ventilator mode, pulmonary hypertension, mild tricuspid regurgitation, vasoactive drug use, heart rate, systolic blood pressure, diastolic blood pressure, MAP1, PEEP, or MAP2 (all P > 0.05), as shown in **Table 5**.

Discussion

PICC is a commonly used intravenous access tool due to its safety, ease of use, and extended dwell time, providing effective venous access and reducing vascular damage for LBWIs receiving treatment [21, 22]. However, using PICC for CVP measurement is an invasive procedure with risks of catheter malposition. This study found a 36.67% rate of PICC malposition (44/120) among LBWI cases, which can lead to complications such as fluid extravasation, occlusion, thrombosis, and phlebitis, adversely affecting treatment outcome. Severe malposition may even result in pericardial or pleural effusion, potentially causing cardiac tamponade, a life-threatening condition for premature infants.

Multivariate logistic analysis identified gestational age, birth weight, SD, S/L ratio, and CVP as significant factors influencing PICC catheterization outcome in LBWI. Lower birth weight, shorter body and vein length, and measurement deviations contribute to increased PICC malposition risk. Tao et al. [23] found that the distance between the PICC tip and the heart entrance was influenced by weight and length changes in preterm infants, with significant cor-

Table 5. Correlation analysis between ultrasonic measurement of IVC S/L and measurement of CVP and clinical factors

Factor	Ultrasonic measurement of S/L		PICC measurement of CVP	
	r	P	r	P
Sex	-0.079	0.392	-0.053	0.564
Gestational age (weeks)	0.278	0.002	-0.096	0.297
Birth weight (g)	-0.220	0.016	0.067	0.466
Prenatal hormone use	-0.090	0.330	-0.132	0.150
Maternal hypertension	-0.066	0.474	0.012	0.892
Ventilator mode	0.354	< 0.001	0.001	0.230
Mild pulmonary hypertension	-0.157	0.087	-0.134	0.144
Mild tricuspid regurgitation	0.228	0.012	0.155	0.091
Vasoactive drug	0.325	< 0.001	0.179	0.051
Heart rate (times/min)	0.050	0.586	-0.024	0.719
Systolic blood pressure (mmHg)	-0.099	0.282	-0.109	0.236
Diastolic blood pressure (mmHg)	-0.003	0.974	-0.060	0.514
MAP_1 (mmHg)	0.015	0.869	0.075	0.415
PEEP (cmH_2O)	-0.081	0.378	0.089	0.332
MAP_2 (cmH_2O)	0.007	0.936	0.052	0.571

Note: SD, small diameter; LD, large diameter; S/L, small diameter/large diameter; MAP_1, mean arterial pressure; PEEP, positive end expiratory pressure; MAP_2, mean airway pressure; CVP, central venous pressure; PICC, peripherally inserted central catheter.

relations between tip displacement and weight changes. Due to the LBWI's smaller IVC and its substantial respiratory variability, catheter po sitioning can be particularly susceptible to external factors like body movement and respiration during PICC insertion. Changes in IVC diameter can reflect blood volume status; reduced blood volume decreases the IVC diameter and increases the collapse index, complicating catheter placement and increasing the likelihood of malposition.

The smaller IVC in LBWI increases puncture and catheterization difficulty, requiring a higher skill level to ensure correct catheter placement. Inappropriate techniques, such as excessive insertion speed or insufficient depth, may contribute to malposition [24]. Additionally, CVP reflects pressure changes in the right atrium or vena cava, and abnormal CVP fluctuations during PICC insertion - such as sudden pressure changes - may shift catheter positioning, leading to malposition. LBWI with low CVP may have poorer blood volume status, heightening malposition risk during catheterization [25].

Currently, in the clinical management of critically ill pediatric cases, evaluating hemodynamic status is essential, with CVP often used as an indicator of preload. This helps assess intravascular fluid volume and guide fluid management decisions [26, 27]. The expert consensus from the Cardiovascular Dynamics Branch of the European Society of Children and Neonatal Intensive Care recommends real-time CVP monitoring in all clinically unstable children who do not respond to initial hemodynamic therapy, as changes in CVP trends provide valuable information on cardiovascular pathophysiology [28, 29].

For LBWI, incomplete physical development often predisposes them to pathophysiologic states like volume overload, while their small size and unstable hemodynamics make early and accurate CVP assessment challenging through conventional methods [30]. Invasive CVP measurement in LBWI poses risks to neonatal health and presents technical difficulties, limiting its clinical application in neonatology [16, 31, 32]. Therefore, establishing a reliable, noninvasive CVP estimation method is critically needed.

Ultrasonic measurement of the IVC, developed in the 1960s as a non-invasive diagnostic technique, has gradually been adopted in related clinical fields. Given the challenges of CVP assessment in neonates, studies by Sato et al.

[33] and Mulgoo et al. [34] demonstrated that ultrasound-measured IVC parameters show good correlation with neonatal CVP. This study found that while LD had no significant correlation with CVP, both SD and the S/L ratio were positively correlated with CVP. These results suggest that the non-invasive S/L ratio measurement of the neonatal IVC in LBWI may be comparable to invasive CVP assessment, providing a reliable basis for evaluating CVP levels.

Ultrasound-based cardiac function or functional echocardiography is non-invasive, readily accessible at the bedside in intensive care, and enables real-time hemodynamic assessment. This approach supports cardiac function and preload assessment, cardiac output and fluid responsiveness estimation, pulmonary systolic blood pressure measurement, and continuous treatment monitoring, making it highly effective in guiding management in critically ill neonates [35].

In this study, the S/L ratio was significantly correlated with gestational age, birth weight, ventilator mode, tricuspid valve regurgitation, and vasoactive drug use ($P < 0.05$). However, CVP measurements showed no significant correlation with gender, gestational age, birth weight, prenatal hormone use, maternal hypertension, ventilator mode, pulmonary hypertension, mild tricuspid regurgitation, vasoactive drug use, heart rate, systolic and diastolic blood pressure, MAP1, PEEP, or MAP2. This suggests that tricuspid regurgitation and vasoactive drugs may induce only minor hemodynamic changes, which, given the small body size and minimal CVP fluctuation in LBWI, elicit limited hemodynamic response. Additionally, the correlation of the S/L ratio with gestational age, birth weight, ventilator mode, tricuspid regurgitation, and vasoactive drugs suggests that IVC diameter variations may be influenced by both hemodynamic pressure and changes in pulmonary pressure during assisted ventilation.

This study has several limitations: (1) The study sample is limited in both size and source, which may narrow the generalizability of the findings; (2) The cross-sectional approach lacks the support of continuous and dynamic longitudinal data; (3) Due to the lack of a standardized non-invasive approach to assess right ventricular function, we cannot completely rule out the possibility of undetected right heart failure in some infants. Most infants in the NICU who require preload assessment are mechanically ventilated. In this study, all CVP and IVC diameter measurements and correlation calculations were conducted with ventilator assistance. However, preload assessment may also be necessary for infants who are breathing independently, and this study did not investigate whether spontaneous breathing affects the correlation between S/L ratio and CVP.

In summary, birth weight, SD, S/L ratio, and CVP are influential factors in ectopic PICC placement in LBWI. There is a significant correlation between the ultrasound-measured SD and S/L ratio of the IVC and the CVP measured by PICC in LBWIs.

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Disclosure of conflict of interest

None.

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