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Point-of-care ultrasound estimation of gastric residual volume in preterm infants: development of a calculation model

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Abstract

Background The aspiration of gastric residual volume through the gastric tube increases the risk of feed interruption episodes, prolongs the time needed to achieve full enteral feeding and regain birth weight, and may potentially damage the gastric mucous. This study aimed to develop a point-of-care ultrasound-based model to calculate gastric residual volume in preterm infants.

Methods This observational study enrolled 100 preterm infants who fed by gastric tube. The collected data included general characteristics of the preterm infants, the antral cross-sectional area in the right lateral position within 30 min prior to feeding and the gastric residue volume measured through gastric tube. A linear regression analysis was conducted to assess the relationship between the antral cross-sectional area and the aspirated gastric residual volume, with the calculation of the Pearson correlation coefficient. A stepwise linear multiple regression was employed to model the relationship between the suctioned residual volume and the parameters under consideration. Subsequently, we utilized the Bland-Altman plot to assess the agreement between the gastric residual volume measured by aspiration and our model, respectively.

Results Overall, 89 preterm infants were included in the final analysis. Pearson correlation analysis revealed a significant correlation between the gastric antral cross-sectional area in the right lateral decubitus position and the suctioned volume ($P < 0.001$; correlation coefficient: 0.905). We developed an ultrasound calculation model as follows: Volume (ml)= -3.74 + 9.08 × Gastric Antral Cross-Sectional Area (measured in the right lateral decubitus position) (cm2). When comparing the ultrasound calculated volume and suctioned volume, the mean was 0.05 ml kg-1 and the limit of consistency was − 1.59 to 1.69 ml kg-1 between the ultrasound calculated volume and suctioned one.

Conclusion The use of ultrasound to assess gastric residual volume (GRV) offers a promising alternative to gastric tube suction, potentially reducing associated complications and enhancing enteral nutrition management in preterm infants. Our study represents a pioneering effort in the development of a point-of-care ultrasound-based calculation model for non-invasive GRV assessment in this vulnerable population.

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Significance

What is already known on this topic

1. Nurses mainly assess the gastric residual volume by aspirating the gastric contents via an gastric tube, which interferes with the rehabilitation process to a certain extent.
2. There is a significant relationship between the antral cross-sectional area and gastric residual volume.
3. Ultrasound examination of the antrum is an easy-to-perform tool that may allow reliable assessment of the gastric residual volume in both adults and children.

What this study adds

1. This study demonstrates that the cross-sectional area of the gastric antrum in the right lateral decubitus is a crucial factor for estimating gastric residual volume in preterm infants.
2. This study established a model for calculating gastric residual volume in premature infants using ultrasound.

How this study might affect research, practice or policy

1. The findings of this study could potentially impact the assessment of gastric residual volume in preterm infants and facilitate the implementation of intestinal feeding.

Keywords Point-of-care ultrasound, Gastric residual volume, Preterm infants, Non-invasive assessment, Calculation model, Enteral nutrition management

Introduction

Appropriate management of early nutritional support is particularly crucial for preterm infants, as it significantly impacts their growth and development [1, 2]. Evidence indicates that early initiation of enteral feeding following birth promotes gastrointestinal system maturation, reduces nutritional intolerance, and enhances neural developmental outcomes, particularly in very low birth weight (VLBW) preterm infants [3–5]. However, the implementation of early enteral feeding is often challenged by feed intolerance, which primarily results from gastrointestinal immaturity and reduced intestinal motility [6–7]. Clinically, feeding intolerance is identified when gastric residual volume (GRV) exceeds 50% of the previous feeding volume or when accompanied by clinical symptoms such as abdominal distension or vomiting [8]. Importantly, GRV serves as a quantifiable clinical parameter that reflects gastric emptying efficiency and nutrient absorption capacity [9]. Therefore, meticulous monitoring of GRV is essential for optimizing nutritional management in preterm infants.

Despite the clinical importance of GRV monitoring, there is currently no standardized or universally accepted measurement method [10]. In clinical practice, the most commonly employed technique in Neonatal Intensive Care Units (NICUs) involves intermittent aspiration of gastric contents through an indwelling gastric tube, performed primarily by nursing staff [11, 12]. However, this conventional approach presents several clinical challenges: (1) it increases the risk of unnecessary feeding interruptions [13], (2) may cause mechanical injury to the gastric mucosa [14], (3) prolongs the time required to achieve full enteral feeding [15], and (4) potentially compromises the overall rehabilitation process [16]. These limitations highlight the need for developing less invasive and more reliable GRV monitoring techniques in neonatal care.

Gastric ultrasound has emerged as a valuable point-of-care tool for qualitative assessment of gastric contents and quantitative prediction of gastric fluid volume, demonstrating significant utility in guiding enteral feeding management in adult populations [17]. Building upon this foundation, Beck et al. [18] conducted a pioneering study evaluating the feasibility of ultrasound for quantifying small volumes of gastric contents. Further advancing this field, Perrella et al. [11] established a significant correlation between antral cross-sectional area (CSA) and feeding volumes. These findings were corroborated by Van de Putte et al. [19], who demonstrated a consistent association between antral CSA and GRV measurements. Despite these advancements in adult and pediatric populations, there remains a critical gap in neonatal care, as no validated point-of-care ultrasound calculation model currently exists for GRV assessment in preterm infants.

To address this significant clinical need, the present study aims to develop and validate a novel bedside ultrasound-based model for accurate calculation of gastric residual volume in preterm infants. This innovative approach seeks to overcome the limitations of traditional GRV measurement methods while providing a non-invasive, real-time monitoring solution tailored to the unique physiological characteristics of premature neonates.

Methods

Study design and setting

This single-center observational study approved by the Ethics Committee of the First Affiliated Hospital of the Zhengzhou University (Ethics Number: 2022 – 0493), included preterm infants who were hospitalized at the Neonatal Intensive Care Unit (2) of the First Affiliated Hospital of Zhengzhou University between July and

December 2022. Written informed consent was obtained from the guardians prior to acquisition of ultrasound images.

Participants

The study subjects were premature infants born and admitted to the neonatal intensive care unit at the First Affiliated Hospital of Zhengzhou University. Inclusion criteria were as follows: (I) Gestational age less than 37 weeks; (II) Occurrence of feed intolerance after enteral nutrition, requiring gastric tube feeding. Feed intolerance is clinically characterized by specific indicators, including: (1) increased gastric residual volume, defined as a single measurement exceeding 50% of the previously administered feeding volume; (2) altered gastric residual characteristics, such as bilious- or blood-stained appearance; (3) abdominal distension; and/or (4) emesis. This comprehensive definition encompasses both quantitative and qualitative aspects of gastric residual evaluation along with associated clinical manifestations [8]; (III) Stable vital signs without severe complications, such as neurological complications (Grade III or IV intraventricular hemorrhage, periventricular leukomalacia, etc.), chromosomal or genetic abnormalities, complex congenital heart disease (Tetralogy of Fallot, pulmonary stenosis, etc.), congenital gastrointestinal malformations, or necrotizing enterocolitis.

Ultrasound examination of the antrum

All gastric ultrasound assessments were conducted by an experienced investigator who had performed gastric ultrasonically in more than 200 cases. The antral CSA was measured by a portable color Doppler ultrasound (LOGIQ E R7 PRO) unit within 30 min prior to feeding. Measuring the cross-sectional area of the gastric antrum in the right lateral decubitus position in preterm infants can effectively minimize interference from intragastric gas, thereby improving the accuracy of the assessment [20].

The left lower sternal end of the infant served as the body surface positioning marker for the ultrasound probe, while the abdominal aorta, superior mesenteric vein, and left lobe of the liver (within the abdominal cavity) were utilized as positioning markers for locating the gastric antrum within the body [21]. The antral cross-sectional area (CSA) was indirectly monitored by measuring the longitudinal(D1) and anteroposterior(D2) cross-sectional diameters of a single section of the gastric volume. Consequently, the gastric antral CSA (A) was calculated in all subjects using the formula: $A = \pi \times (D1mean \times D2mean/4)$. At this level, the scan showed the stomach shaped as either a circle or an ellipse (Fig. 1).

Suctioned gastric volume via the gastric tube

The GRV was assessed based on the suctioned gastric volume obtained from the gastric tube. A 10mL syringe was attached to the gastric tube, and gentle suction was initially applied in the right lateral position (RLD), followed by suction in the supine position. We also evaluated gastric residual volume using a qualitative grading system [22], aiding in the determination of any gastric residue presence. A grading of 0, 1, or 2 was applied as follows: Grade 0, no fluid visible in the antrum in either the supine or the RLD; Grade 1, antral fluid visualised only in the RLD; or Grade 2, antral fluid visualized both in the supine and in the RLD.

Dependent variable

At the beginning of this study, we had selected 10 possible predictors: gestational age, the number of days since birth, weight, length at ultrasound investigation, type of milk (human milk or formula milk), the antral CSA in the right lateral position, volume of feed provided at last

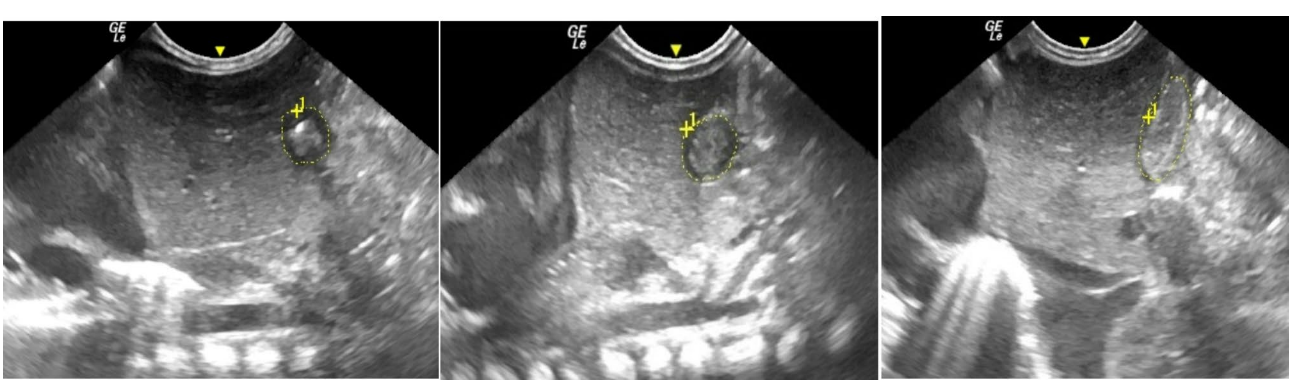

Fig. 1 Gastric antral cross-sectional area measurements. Left(**a**) empty stomach: gestational age at birth: 26.6 weeks, number of days since birth at the time of image acquisition: 24 days. weight: 1161 g. and RLD-CSA: 0.37 cm^2. Middle(**b**) 0.7 ml drained: gestational age at birth: 31.1 weeks, number of days since birth at the time of image acquisition: 17 days, weight: 1760 g. and RLD-CSA: 0.58 cm^2. Right(**c**) 3.5 ml drained: gestational age at birth: 29 weeks, number of days since birth at the time of image acquisition: 31 days, weight: 1980 g, and RLD-CSA: 1.03 cm^2. CSA, cross-sectional area; RLD, right lateral decubitus.

meal, feeding interval, duration of last meal provided, the number of times enteral feeds were discontinued in 24 h.

Statistical analysis

Kolmogorov-Smirnov test was used to check normality of the data distribution. A linear regression analysis was performed between the antral CSA in the right lateral decubitus position and the aspirated gastric volume, with calculation of the Pearson correlation coefficient. A stepwise linear multiple regression was used to model the relation between suctioned volume and independent variable. For each test, $P < 0.05$ was considered statistically significant. We then developed a calculation model for GRV in preterm infants using significant variables in multiple regression analyses. To verify agreement between the calculated and the suctioned GRV, we used a Bland-Altman analysis which plots the difference between calculated and suctioned volumes for each patient vs. the mean volume of the calculated and suctioned values [23]. All statistical analyses were performed using SPSS.25 statistical software version.

Results

Baseline clinical characteristics

During the study period, a total of 100 preterm infants were initially enrolled. Of these, 11 were excluded due to the inability to obtain clear gastric antrum images, resulting in 89 infants being included in the final analysis. The clinical characteristics of the included infants were as follows: median gestational age, 32.1 weeks (inter quartile range [IQR], 30.1–33.4 weeks); median weight, 1510 g (IQR, 1290–1760 g); median postnatal age, 13 days (IQR, 7.5–20.5 days); and median length at the time of ultrasound investigation, 39.5 cm (IQR, 37.7–42 cm). Among the infants, 71 (79.8%) were fed formula milk, while 18 (20.2%) received human milk (Table 1).

Table 1 Subject characteristics

	***N* = 89**
Gestational age (weeks)	32.1(30.1–33.4)
Number of days since birth (days)	13(7.5–20.5)
Length at ultrasound investigation (cm)	39.5(37.7–42)
Weight (g)	1510(1290–1760)
Type of milk	
Milk powder for premature infants	46(51.7%)
Breast milk	18(20.2%)
Special types of milk	25(28.1%)
Respiratory support	
Mechanical ventilation	0(0%)
Noninvasive ventilation	55(61.8%)
Oxygen inhalation	10(11.2%)
None	24(27%)
Volume of feed provided at last meal (ml)	5 (1–13)
Total milk intake in 24 hours (ml)	50 (12–156)
Feeding interval(h)	2 (2–3)
Duration of last meal provided (min)	1.4 ± 1.1
The number of times enteral feeds were discontinued in 24hours(times)	1.0 ± 1.7
RLD CSA(cm^2)	0.6 ± 0.3

CSA, cross-sectional area; RLD, right lateral decubitus

Development an ultrasound-based gastric residual volume calculation model for preterm infants

According to the stepwise linear multiple regression analysis, statistical results showed that gestational age, number of days since birth, weight, length at ultrasound investigation, type of milk fed, volume of feed provided at last meal, feeding interval, duration of last meal provided, and the number of times enteral feeds were discontinued in 24 h were not associated with the GRV in preterm infants ($P > 0.05$). The antral CSA in the right decubitus position was found to be significantly related to GRV ($P < 0.001$; correlation coefficient: 0.905) (Fig. 2).

We conducted multiple regression imputation for the US calculation of GRV: Volume (ml)= -3.74 + 9.08 × Gastric Antral Cross-Sectional Area (measured in the right lateral decubitus position) (cm^2). The coefficient of determination (R^2) of this model was 0.817; $P < 0.001$ (Table 2).

Assessment of agreement between US calculated and suctioned gastric residual volumes

We performed a Bland-Altman analysis of the agreement between suctioned GRV per kilogram and US measured GRV per kilogram in our patients. The mean difference and the lower (mean difference + 1.96 SD) and upper (mean difference-1.96 SD) limits of agreement were 0.05 ml kg^{-1}(95%CI: -0.13 to 0.22), -1.59 ml kg^{-1} (95% CI: -1.89 to -1.29) and 1.69 ml kg^{-1} (95% CI: 1.38 to 1.99), respectively (Fig. 3).

Discussion

Our study established a significant correlation between antral cross-sectional area (CSA) measured in the right lateral decubitus position and gastric residual volume (GRV) in preterm infants ($r = 0.905$, $p < 0.001$). Based on this finding, we developed and validated a novel ultrasound-based predictive model for accurate GRV estimation in preterm infants. This pioneering research represents the first development of a point-of-care ultrasound calculation model specifically designed for GRV assessment in the neonatal population. Notably, this study addresses a critical clinical gap.

Several criteria have been employed to delineate a substantial volume of GRV, encompassing thresholds such as ≥ 2 ml per kg of the infant's weight, > 2 ml or 3 ml depending on the infant's weight, > 30% of the

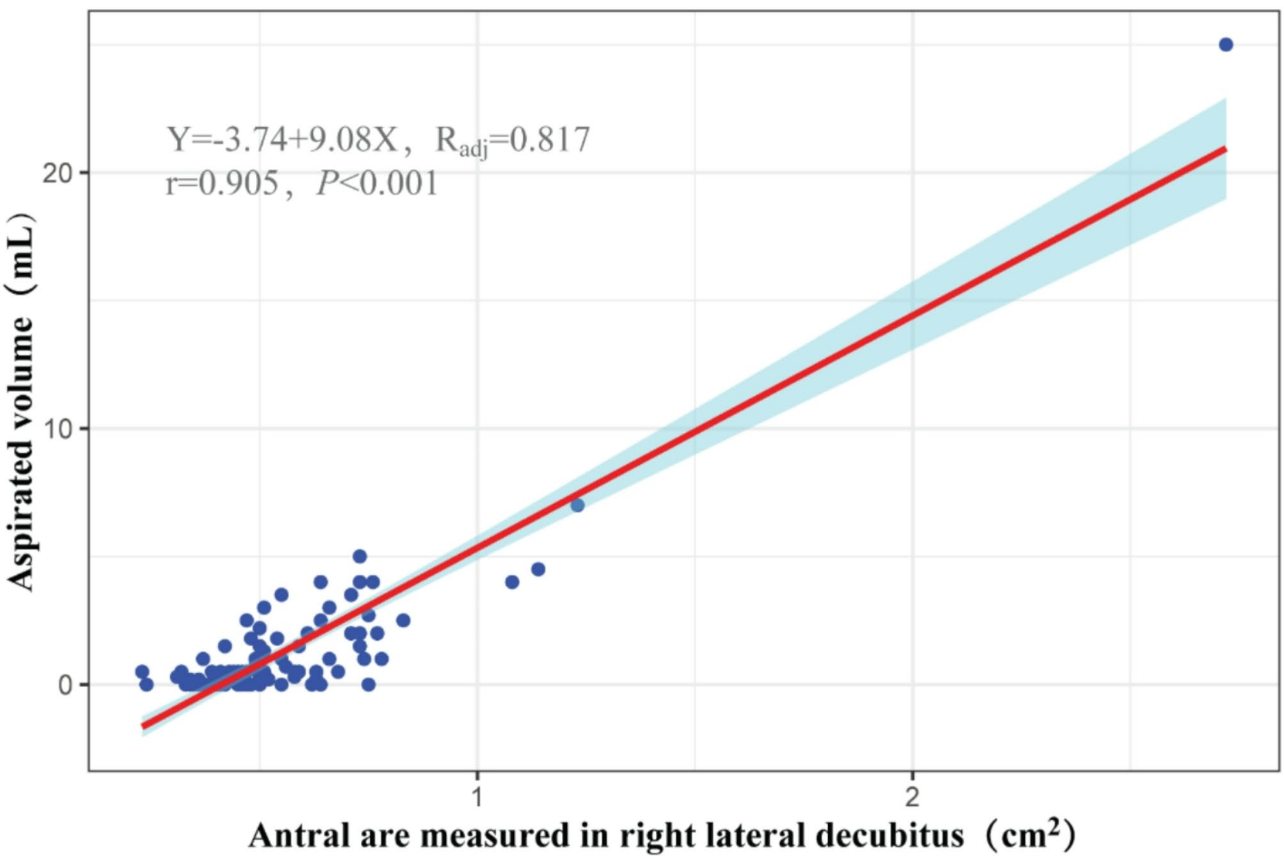

Fig. 2 Correlation of the aspirated gastric residual volume with the antral cross-sectional area measured in right lateral decubitus

Table 2 Regression model statistics for the suctioned gastric volume

Independent Variable	Coefficient	Standard error	t	*P*-value
Intercept	-3.741			
RLD-CSA	9.076	0.457	19.844	<0.001

previous feed volume, and >50% of the cumulative feed volume given during the specified time interval [24–26]. However, presently, there is no consensus on the recommended threshold for GRV, nor is there a universally accepted definition of what constitutes a normal or acceptable volume of residuals.

Recent studies have questioned the utility of routine monitoring of GRV, but lack robust evidence [13, 15, 16]. They show that the fear of NEC based on signs of "feed intolerance" on routine monitoring of GRV probably dose more good than harm (sub-optimal nutrition due to frequent stopping of feedings). However, other studies have shown that a large GRV is still an observational indicator of early NEC and a criterion for judging feeding intolerance [8, 27–29]. Currently, Guidelines recommend that the GRV should be evaluated promptly in preterm infants who develop bloating, vomiting, regurgitation, irritability, lethargy, frequent apnea, bradycardia and other symptoms [15]. In our study, GRV was assessed using point-of-care ultrasound to measure the cross-sectional area of the gastric antrum, a method recognized as non-invasive and reliable [17, 30]. Furthermore, the coefficient of determination (R^2) for our model was 0.817, indicating that the model accounts for 81.7% of the variability in the target (dependent) variable. We conclude that our newly developed calculation model is particularly well-suited for estimating GRV in preterm infants.

Our measurement method is not associated with complications in most cases. Firstly, in our study, ultrasound examinations were seamlessly incorporated into routine abdominal assessments for preterm infants, eliminating the need for additional tests. This approach is equally applicable to other pediatric populations. S. Giordano [31] reported the case of a 2-year-old boy who developed acute pancreatitis following rotavirus gastroenteritis. After an abdominal ultrasound evaluation revealed no pathological signs, fatty and protein-rich foods were gradually reintroduced and well-tolerated. In another study, an infant with a contiguous gene deletion syndrome at Xp22.31, was diagnosed with pyloric stenosis through antropyloric ultrasound examination. Timely surgical intervention was performed, leading to effective treatment [32]. Secondly, in our study, we selectively

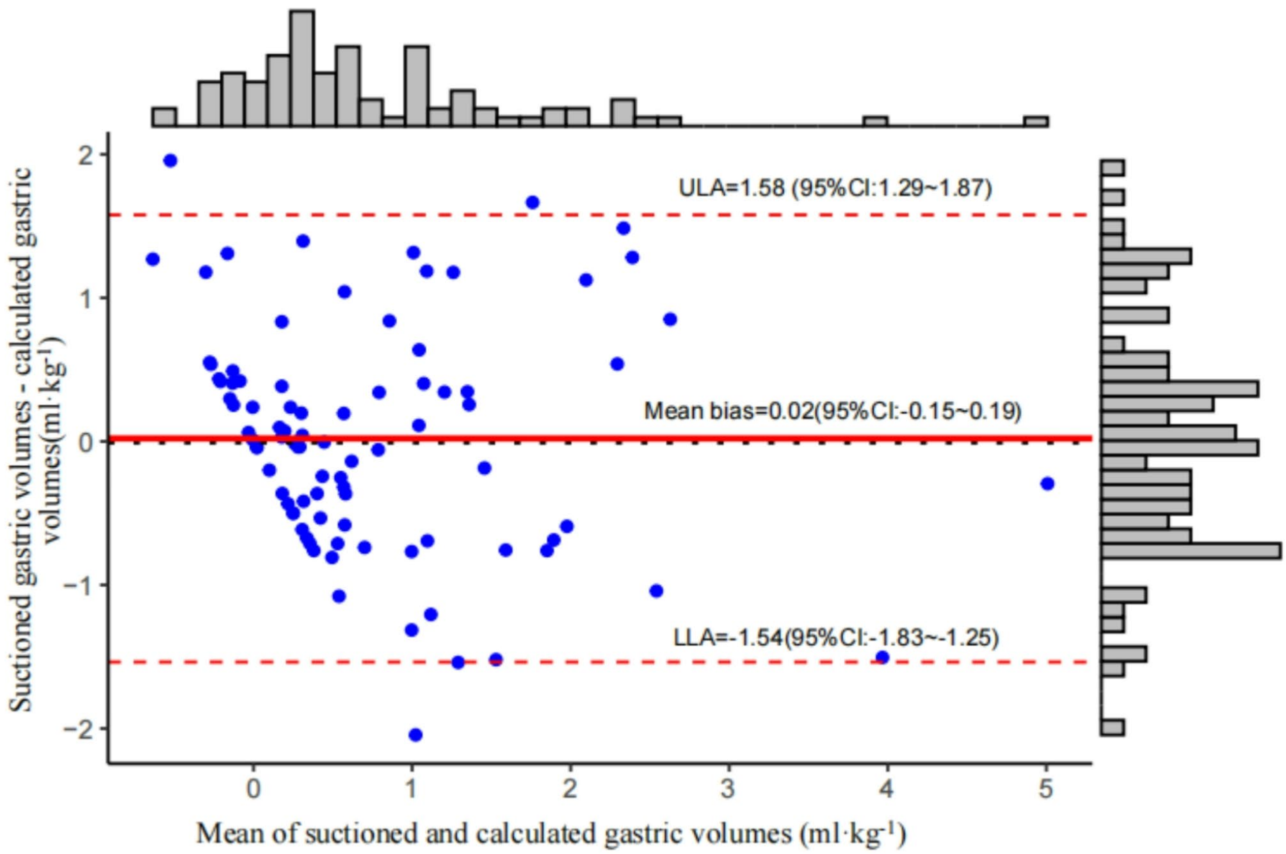

Fig. 3 Bland-Altman analysis plots the difference between US calculated and suctioned fluid volumes for each patient vs. the mean volume of the calculated and suctioned values

performed ultrasound measurements to assess GRV in preterm infants. Elia S et al. [33] demonstrated that selective monitoring of GRV in premature infants can prevent unnecessary feeding interruptions and promote better weight gain. The use of ultrasound to measure GRV eliminates the risk of gastric mucous damage and infection associated with gastric tube insertion, thereby supporting optimal growth and development. Thirdly, we strictly adhere to disinfection and isolation protocols during examinations while closely monitoring any changes in the child's vital signs. Our procedures typically last less than five minutes, minimizing discomfort for the infants.

Here are certain limitations in our study. Firstly, quantifying gastric contents with blindly suctioned samples may not accurately estimate GRV, highlighting the need for further investigation. Secondly, our study did not investigate the optimal frequency, timing, and duration of ultrasound evaluations. In future research, we will determine these parameters in order to develop a standardized protocol for their routine use in assessing GRV.

Conclusions

In summary, this study established a model for calculating gastric residual volume in premature infants using ultrasound. No ultrasound-based method currently exists for GRV calculation in preterm infants.

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Author contributions

study design: LC, YH; data collection: CL, MS, YL, YH, LC; ultrasound measurements: YH, LC; data analysis: LC, YH; writing of the first draft of the paper: LC, YH; revision of the paper critically for important intellectual content: LC, YH, HZ.

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Data availability

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
This single-center observational study approved by the Ethics Committee of the First Affiliated Hospital of the Zhengzhou University (Ethics Number: 2022 – 0493). Written informed consent was obtained from the guardians. All methods were performed in accordance with the ethical standards as laid down in the Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent for publication
Written informed consent for publication was obtained.

Competing interest
The authors declare that they have no competing interests.

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