Review

Med Ultrason 2026, Vol. 28, no. 1, 80-87
DOI: 10.11152/mu-4538

Accuracy and precision of ultrasonic cardiac output monitor versus echocardiography for cardiac output measurement in neonates: a systematic review and meta-analysis

Na Wang, Bin Tang, Hongjuan Zhang, Bo Wang, Jia Zhang

Department of Neonatology, The Affiliated Suqian First People's Hospital of Nanjing Medical University, Suqian, Jiangsu, China

Abstract

Aim: To perform a systematic review and meta-analysis of the consistency between ultrasonic cardiac output monitor (USCOM) and echocardiography in monitoring neonatal cardiac output. **Material and methods:** PubMed, Embase, Web of Science, Cochrane, Wanfang, Chinese National Knowledge Infrastructure Database, and Chinese Science and Technique Journal Database were searched from the inception of the databases to November 2024. Two reviewers independently performed study selection, data extraction, and risk of bias assessment. Method-comparison studies evaluating USCOM versus echocardiography in neonates were included. Pooled mean bias (accuracy), standard deviation, and mean percentage error (precision) of the included studies were calculated using a fixed-effects model. **Results:** Six of the 774 identified studies were included in the qualitative analysis, and four studies were included in the meta-analysis. The overall pooled bias and percentage error for left ventricular output measurements were -7.7±13.5 mL/kg/min (95% limit of agreement: -34.2 to 18.8 mL/kg/min) and 31.2%, respectively, while the overall pooled bias and percentage error for right ventricular output measurements were 40.5±21.3 mL/kg/min (95% limit of agreement: -1.2 to 82.2 mL/kg/min) and 35.1%, respectively. **Conclusion:** USCOM may overestimate right ventricular output trend, while left ventricular output measurement agreement is slightly better.

Keywords: cardiac output; neonatology; hemodynamic monitoring; ultrasound; meta-analysis

Introduction

Cardiac output (CO) monitoring is an important part of cardiovascular monitoring. For clinical measurement of CO and circulation in adults, intermittent pulmonary artery thermodilution and transpulmonary thermodilution (TPTD) have long been regarded as the gold standard methods [1]. However, these invasive monitoring methods are not suitable for hemodynamic monitoring of neonates. On the other hand, although two-dimensional echocardiography is a widely accepted and reliable non-invasive hemodynamic monitoring technique, it requires professional training [2,3].

As a clinical bedside device for non-invasive monitoring of cardiac function and hemodynamics, the ultrasonic cardiac output monitor (USCOM) uses continuous Doppler ultrasound technology to calculate the stroke volume, CO, and other indicators by measuring the ejection velocity integral of the aorta/pulmonary artery and multiplying the valve cross-sectional area. It has been widely used in adult and child care units [4]. USCOM uses continuous-wave Doppler, whereas echocardiography is based on the pulse-wave Doppler principle. In comparison with echocardiography, USCOM is simpler to perform and requires no professional ultrasound staffing. Although this technique has shown good correlation for adults and children [5], the correlation for neonates is not clear.

Received 30.06.2025 Accepted 21.07.2025
Med Ultrason
2026, Vol. 28, No 1, 80-87
Corresponding author: Jia Zhang
The Affiliated Suqian First People's Hospital of Nanjing Medical University,
120 Suzhi Road, Suqian,
223800, Jiangsu, China
E-mail: ZJsuqian8383@126.com

We conducted a systematic review and meta-analysis of studies comparing generally accepted USCOM and echocardiographic reference methods in neonatal populations. We primarily evaluated the accuracy (mean bias) and precision (standard deviation [SD] of the bias) of CO measured by USCOM in comparison with that measured using echocardiographic methods. If the percentage error (PE) was less than or equal to 30%, the precision was defined as acceptable [6].

Material and methods

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Supplementary Table SI) [7] and registered on the PROSPERO database (registration number: CRD 42024543428).

Eligibility criteria

The eligibility criteria were as follows: (1) studies comparing USCOM and echocardiography for measuring CO; (2) studies that reported bias, SD of bias, and PE using Bland–Altman analysis; (3) studies conducted in neonates (both full-term and preterm) that reported demographic data (gestation age, patient characteristics, study setting, and sample size); (4) studies conducted in humans; and (5) studies published in full in Chinese or English. No restrictions were imposed on the date of publication. The exclusion criteria were as follows: (1) studies in which data were presented in the form of cardiac index or stroke volume values rather than CO values; (2) papers for which the full research was not accessible.

Information sources and search

Two investigators conducted systematic searches in PubMed, Embase, Web of Science, Cochrane, Wanfang, Chinese National Knowledge Infrastructure Database, and Chinese Science and Technique Journal Database to identify studies published in English or Chinese as of November 23, 2024. A combination of MeSH terms and other equivalent terms were used together with truncated search terms and Boolean operators to achieve broader coverage, yielding the following search string: "Continuous-wave Doppler Ultrasound Monitor" OR "ultrasonic cardiac output monitor*" OR "USCOM" OR "ultrasound cardiac output monitor*" AND ("infant, newborn" OR "newborn*" OR "baby*" OR "premature" OR "preterm" OR "low birth weight") AND ("cardiac output" OR "output cardiac" OR "cardiac index" OR "stroke volume" OR "smith madigan inotropy index").

Study selection

Titles and abstracts were screened by two independent researchers, and disagreements were resolved by consensus. Full-text articles were searched and independently evaluated by two reviewers according to the predefined eligibility criteria listed above. Differences were resolved through discussion with a third researcher.

Data collection process

Two authors independently extracted data from the screened articles, including the main results of the study (bias of left ventricular output [LVO] or right ventricular output [RVO] by USCOM and echocardiography, SD of the bias or 95% limits of agreement [LOA], and PE), patient characteristics (gestational age, birth weight), publication year, author, sample size, and data points. In this meta-analysis, the mean CO, bias, LOA, SD, and PE of both the left and right ventricles, as ascertained through USCOM and echocardiography, were calibrated in accordance with the following formula:

$$\text{Mean CO} = \frac{CO_{USCOM} + CO_{echocardiography}}{2}$$

$$\text{Bias} = CO_{USCOM} - CO_{echocardiography}$$

$$\text{LOA} = \text{bias} \pm 1.96\,\text{SD}$$

$$\text{SD} = \frac{\text{UpperLOA} - \text{LowLOA}}{1.96 \times 2}$$

$$\text{PE} = \frac{\text{SD of bias between methods}}{\text{Mean CO}} \times 1.96 \times 100\%$$

If a study reported only bias and SD, the PE was recalculated using our definition. The above equation was used to calculate the missing information. If the data could not be calculated, they were extracted from the Bland–Altman plot.

Risk of bias in individual studies

To assess the risk of bias in individual studies, we used the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) guidelines. Two researchers evaluated the quality of all the included literature. The evaluation tool was the bias assessment tool for diagnostic test accuracy studies (www.bris.ac.uk/quadas). In accordance with the "Process of QUADAS-2 Tool for Tailoring System Review," the QUADAS-2 was tailored and modified as required (Supplementary Table SII) [8,9]. Bias and applicability areas of risk were classified as low risk, high risk and undefined risk. Disagreements in risk assessments between the two investigators were resolved through discussion with a third investigator.

Summary measures

The summary measures in our analysis were as follows: (1) The accuracy of CO monitoring, which was defined as the bias of CO measurements. (2) The precision of CO monitoring, which was defined as the SD of the bias and the PE. If the PE was less than or equal to 30%, the precision was considered acceptable [6].

Synthesis of results

All statistical analyses were performed using Stata software, version 15.0 (Stata Corporation, College Station, Texas, USA). Data were expressed as mean±SD or bias±SD. $p<0.05$ was considered statistically significant. We synthesized pooled bias, LOA, and PE using effects models and created forest maps. The heterogeneity of the included studies was tested using the q test and shown as an I^2 index (0%, no heterogeneity; 25%-50%, low heterogeneity; 50%-75%, moderate heterogeneity; and >75%, high heterogeneity) [10]. When $p>0.1$ and $I^2<50\%$, a fixed-effect model was used, and a random-effect model was used when $p<0.1$ and $I^2>50\%$. Sensitivity analysis was performed when there was moderate or high heterogeneity ($I^2\geq50\%$).

Additional analysis

Subgroup analysis was performed for term (including near-term) and preterm infants.

Results

Study selection

Database searches as of November 23, 2024, yielded a total of 774 articles after removing duplicates. Next, two investigators read the titles and abstracts to exclude 765 articles. After reading the full texts, three articles were excluded on the basis of the inclusion and exclusion criteria, and the remaining six articles were included in qualitative analysis, of which four were included in the meta-analysis (fig 1).

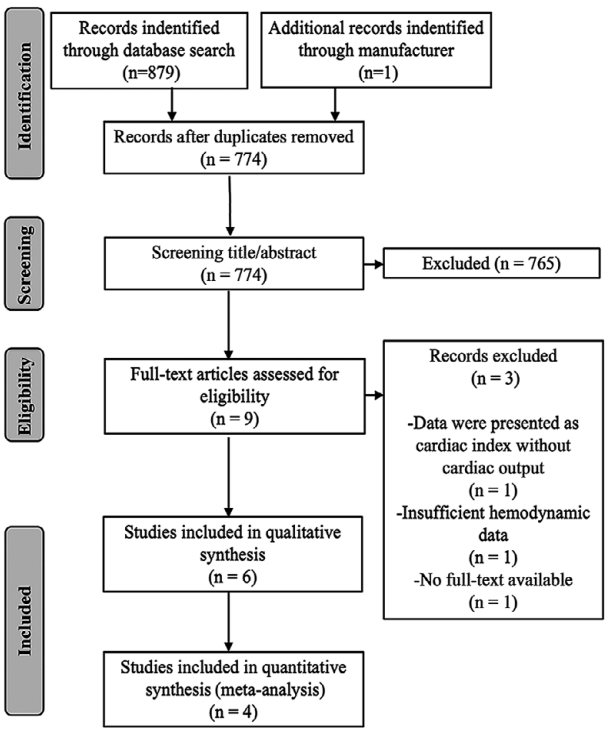


Fig 1. Flow chart of the literature search strategy.

Study characteristics

A total of six studies were included in the qualitative analysis [4,11-15]. Table 1 shows the characteristics of the patients included in these six studies, and four of these studies were included in the meta-analysis [4,12,13,15]. The remaining two studies were not included in the meta-analysis because they reported CO values in mL/min instead of mL/kg/min. The four studies included in the meta-analysis included a total of 297 patients. One study had two different groups of patients (full-term infants and preterm infants); therefore, its results were divided into two groups. One study had an initiation cohort and a validation cohort, so its results were also divided into two groups, and a total of six groups (from four studies) were included in the final analysis. All groups had small sample sizes (median: 42 patients; range: 15-127 patients). Among them, two studies included full-term and near-term infants [12,15]. and the remaining two studies included both full-term and preterm infants [4,13]. All four studies were conducted at the neonatal intensive care unit (NICU).

Risk of bias in individual studies

The quality assessment results of the studies included in the meta-analysis are presented in Supplementary Table SIII. All four studies included in the meta-analysis [4,12,13,15] showed low risk of bias in all domains.

Synthesis of results

The bias, 95% LOA, and PE for LVO measurements in the studies are shown in fig 2. The overall fixed-effects pooled bias and PE were -7.7±13.5 mL/kg/min (95% LOA: -34.2 to 18.8 mL/kg/min) and 31.2%, respectively. Inter-study heterogeneity of the bias was low ($I^2=15.6\%$, $p=0.314$). The bias, 95% LOA, and PE for RVO measurements in the studies are shown in fig 3. The overall fixed-effects pooled bias and PE were 40.5±21.3 mL/kg/min (95% LOA: -1.2 to 82.2 mL/kg/min) and 35.1%, respectively. Inter-study heterogeneity of the bias was low ($I^2=0\%$, $p=0.783$).

Subgroup analyses

Subgroup analysis showed that the fixed-effects pooled bias and PE of LVO measurements were -13.4±17.9 mL/kg/min (95% LOA: -48.5 to 21.8 mL/kg/min) and 38%, respectively, in term/near-term infants and preterm infants. Inter-study heterogeneity was still low ($I^2=40.1\%$, $p=0.171$). The fixed-effects pooled bias and PE of RVO measurements were 41.1±-21.8 mL/kg/min (95% LOA: -1.7 to 83.8 mL/kg/min) and 31.4%, respectively. No inter-study heterogeneity ($I^2=0\%$, $p=0.631$) was observed, as shown in Table II.

Table I. Summary of the included studies.

	Year	N	Patient characteristics	Age, mean±SD or median (range) (weeks)	Data point	Unit of CO measure-ment	Bias±SD		PE (%)	
							LVO	RVO	LVO	RVO
Phillips [11]	2006	37	Preterm infants	NA	NA	mL/min	0 ± 80		3.7	
Patel [12]	2011	56	Newborns with non-cardiac conditions	39 (31–41)	2–122 days	mL/kg/min	-14 ± 54	59 ± 80	43.7	50.8
Zheng [13]	2013	49	Newborns excluding patients with congenital heart disease, intrauterine infection, et al.	32.8±2.6	Within 28 days after birth	mL/kg/min	Term infants: -30.6±25.5; Preterm infants: -24.1±35.6	Term infants: 21.8±52.2; Preterm infants: 29.5±96.4	Term infants: 22.1; Preterm infants: 28.2	Term infants: 31.2; Preterm infants: 50.8
Dong [14]	2015	35	Preterm infants with no congenital heart disease	31 (29–34)	Within 24 hours of invasive ventilation	mL/min	Invasive ventilation: -0.2±102.8; No respiratory support: -20.2±59.75	Invasive ventilation: 174.3±156; No respiratory support: 104±109.9	Invasive ventilation: 54.7; No respiratory support: 26.5	Invasive ventilation: 112; No respiratory support: 67.2
Fraga [15]	2019	65	Neonates with a gestational age of more than 36 weeks and without congenital heart disease	37.8±1.7	2–38.5 days	mL/kg/min	Ascertainment cohort: 95±52; Validation cohort: -29±34	Ascertainment cohort: 64±30; Validation cohort: -4±46	Ascertainment cohort: 43.0; Validation cohort: 31.1	Ascertainment cohort: 15.5; Validation cohort: 28.2
Pliauckiene [4]	2021	127	Newborns without congenital heart defects and invasive respiratory support	34 (23–41)	The seventh day after birth	mL/kg/min	11.9±25.3	-	19.9	-

N, sample size; SD, standard deviation; PE, percentage error; LVO, left ventricular output; RVO, right ventricular output; MA, not available

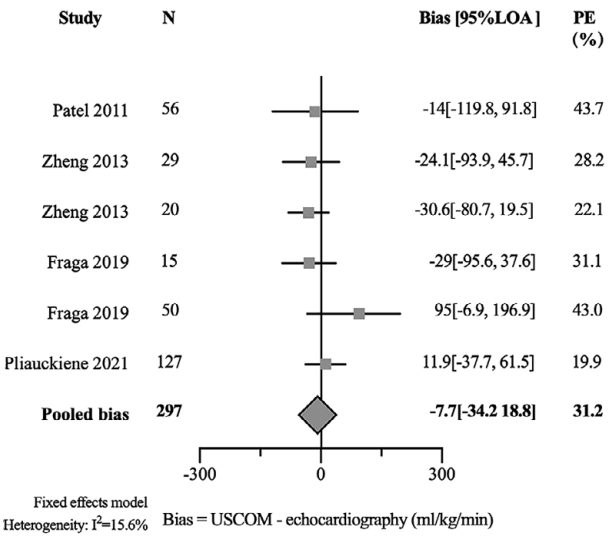


Fig 2. Forest plot showing the bias, 95% limits of agreement, and percentage error of the left ventricular output in the included studies. LOA, limits of agreement; PE, percentage error; USCOM, ultrasonic cardiac output monitor.

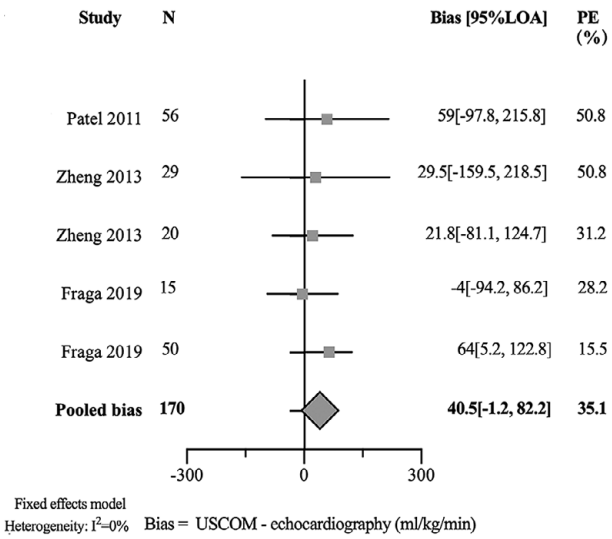


Fig 3. Forest plot showing the bias, 95% limits of agreement, and percentage error of right ventricular output in the included studies. LOA, limits of agreement; PE, percentage error; USCOM, ultrasonic cardiac output monitor.

Table II. Subgroup analysis by age.

	Number of studies	Number of patients	Bias±SD (mL/kg/min)	95 % LOA (mL/kg/min)	PE (%)	I^2 (%)
LVO						
Term/near-term infants	3 [12,13,15]	141	-13.4±17.9	-48.5 ~ 21.8	38.0	40.1
Preterm	1 [13]	29	-24.1±35.6	-93.9 ~ 45.7	28.2	NA
RVO						
Term/near-term infants	3 [12,13,15]	141	41.1±21.8	-1.7 ~ 83.8	31.4	0
Preterm	1 [13]	29	29.5±96.4	-159.5 ~ 218.5	50.8	NA

SD, standard deviation; PE, percentage error; LOA, limits of agreement; LVO, left ventricular output; RVO, right ventricular output; NA, not available.

Discussion

This is the first meta-analysis comparing USCOM with traditional echocardiography for CO monitoring in the neonatal population. The overall pooled bias and PE for LVO measurements were -7.7±13.5 mL/kg/min (95% LOA: -34.2 to 18.8 mL/kg/min) and 31.2%, respectively, while the overall pooled bias and PE for RVO measurements were 40.5±21.3 mL/kg/min (95% LOA: -1.2 to 82.2 mL/kg/ min) and 35.1%, respectively. Both PE values were greater than 30%, and the heterogeneity of the pooled bias between the studies was low. In addition, subgroup analysis showed that the PEs of LVO and RVO for term/near-term infants were 38% and 31.4%, respectively, indicating poor consistency between the two monitoring methods.

The current meta-analysis evaluated the accuracy and precision of the two methods in CO monitoring, an essential diagnostic and management tool for critically ill patients. While ultrasound/Doppler is currently recommended for estimating CO in hemodynamically stable children, invasive monitoring methods are required for initial evaluation in hemodynamically unstable children. In cases requiring absolute measurements of CO in children, TPTD is preferred [16]. However, TPTD is an invasive procedure that is challenging to perform and not suitable for neonates. Among non-invasive monitoring methods, echocardiography is the preferred method for studying the cardiovascular system of newborns [17]. However, in comparison with echocardiography, which requires professional expertise and provides discontinuous measurements, USCOM can be performed without professional expertise and provides continuous measurements. It utilizes continuous-wave Doppler to calculate CO and is specifically designed for rapid and non-invasive assessment of CO. A growing body of research has focused on the application of USOCM in newborns [4,12,18-20], including neonatal hemodynamic monitor-

ing in specific clinical scenarios such as preterm birth and post-PDA surgery [21,22]. In animal trials, USCOM has shown reliable CO monitoring [23]. A recent study has provided reference values for measuring CO in newborns of different gestational ages using USCOM immediately after birth, offering practical clinical significance for rapid bedside assessments in NICUs [24].

However, in this meta-analysis, the mean PE of LVO and RVO measurements was 31.2% and 35.1%, respectively, exceeding the acceptable limit of 30% [6]. In addition, the bias between USCOM and echocardiography may indicate that USCOM overestimates the systematic trend of RVO, while the agreement for LVO measurement was slightly better than that for the right ventricle. This phenomenon could be explained by the fact that USCOM, which is based on continuous-wave Doppler technology, measures stroke volume by integrating the velocity of red blood cells in the aorta or pulmonary artery over time. Inaccuracies may arise from the angle between the ultrasound beam and the blood flow, as well as improper placement of the volume sampling position. Measurement of LVO and RVO was achieved by positioning the USCOM probe in the suprasternal notch and the 2nd to 5th intercostal spaces on the left sternal border to detect blood flow signals across the aortic and pulmonary valve orifices, respectively. The positioning in the 2nd to 5th intercostal spaces on the left sternal border was less accurate than in the suprasternal notch, making it more prone to improper placement of the volume sampling position [12,25]. Therefore, when comparing RVO monitoring, USCOM was more susceptible to bias than echocardiography. Additionally, CO is influenced by various physiological and pathological factors, including heart rate, myocardial contractility, and vascular resistance. Changes in these factors, which may vary with gestational age, weight, and disease status, can lead to temporal and biological variations in CO, thereby affecting the accuracy of the measurement results [26,27]. The RVO measured using USCOM was significantly higher than that measured using echocardiography, and this difference may be attributed to the measurement of blood flow in the pulmonary artery branches [15].

Before each type of CO monitor can be used in clinical practice, its validity must be established. Currently, the Bland-Altman analysis method remains the standard analytical technique employed for CO comparisons [28]. However, the Bland-Altman analysis method does not provide a definitive answer in terms of P-values. The acceptable level of agreement between USCOM and the reference CO technology depends on clinical judgment [29]. This presents a challenge inherent to the Bland-Altman analysis method itself. Furthermore, the use of inaccurate reference techniques will result in wide LOA and high mean error, independent of the precision of USCOM or other new CO monitoring technologies [30,31]. Given the unique characteristics of the neonatal population, echocardiographic monitoring of CO remains the mainstream approach for guiding clinical decisions at present. In light of the possibility that the precision of USCOM may be further refined through future research, the use of USCOM for CO monitoring should still be combined with clinical judgment, rather than relying solely on the conclusions drawn from the Bland-Altman analysis method.

Our results indicate that doctors should exercise caution when making clinical decisions regarding hemodynamic interventions in newborns on the basis of USCOM data. The Bland–Altman analysis indicated that the consistency between CO measurements obtained by USCOM and echocardiography was poor. Subgroup analysis of term/near-term infants showed that the heterogeneity of the mean PEs of LVO and RVO was low, but consistency was equally poor. Therefore, additional validation is needed for the clinical use of USCOM in neonates. To some extent, if USCOM demonstrates significant advantages over the reference technology in terms of operability or cost in clinical practice, the ideal LOA may also be adjusted accordingly [32]. In addition, there is dispersion in CO monitoring during hemodynamic changes, which gradually disappears over time. Therefore, the timing of measurements and their recording are of great importance [33]. Therefore, the continuous measurement feature of USCOM may be utilized for trend monitoring, capturing changes in ΔCO rather than absolute CO, which can better guide clinical decision-making [34,35].

This study had some limitations. First, the possibility of a group selection bias could not be ruled out, since previous studies have shown some correlation between CO and gestational age [20]. In addition, CO may vary with age after birth [36]. However, the average gestational age of the study population included in this meta-analysis was different, and the CO monitoring time was not uniform. Consistency in gestational age and data monitoring time nodes may yield more consistent outcomes between the two detection methods. The second limitation is that the reference method for CO is echocardiography, which requires professional technicians. Assessments by different operators may have resulted in variability among operators, which also exists in the USCOM detection method. One of the included studies did not clearly indicate variability between operators. Thirdly, in many studies, the precision of TPTD was assumed to be 20%, with the PE not exceeding 28.3%, commonly rounded up to 30% [6]. If the reference precision was significantly less than

or greater than 20%, or if there were differences between experimental techniques, it was inappropriate to strictly use the 30% limit for mean PE. The studies we included exhibited considerable variation in mean PE, which may have an impact on the final results of the meta-analysis. Finally, CO was measured in mL/min instead of mL/kg/min in two studies, which were excluded from the meta-analysis, and these exclusions may have influenced the findings.

Conclusions

Our study showed that both non-invasive CO monitoring methods had poor precision in terms of LVO or RVO measurements. Subgroup analysis showed that even after excluding preterm infants, the precision in terms of LVO or RVO measurements in term/near-term infants was still poor. USCOM consistently overestimated CO in comparison with the results obtained using echocardiography. However, continuous monitoring of CO by USCOM may be a useful trend monitor to guide clinical decision-making, and this aspect should be investigated in future studies.

Acknowledgments: This work was supported by the Suqian Sci&Tech Program [grant number SY202303].

Conflict of interest: none

References

1. Elgendy A, Seppelt IM, Lane AS. Comparison of continous-wave Doppler ultrasound monitor and echocardiography to assess cardiac output in intensive care patients. Crit Care Resusc 2017;19:222-229.
2. Tsai-Goodman B, Martin RP, Marlow N, Skinner JR. The repeatability of echocardiographic determination of right ventricular output in the newborn. Cardiol Young 2001;11:188-194.
3. Evans N, Kluckow M. Early determinants of right and left ventricular output in ventilated preterm infants. Arch Dis Child Fetal Neonatal Ed 1996;74:F88-94.
4. Pliauckiene A, Liubsys A, Vankeviciene R, Usonis V. Ultrasonic cardiac output monitor provides effective non-invasive bedside measurements of neonatal cardiac output. J Clin Monit Comput 2022;36:803-807.
5. Chong SW, Peyton PJ. A meta-analysis of the accuracy and precision of the ultrasonic cardiac output monitor (USCOM). Anaesthesia 2012;67:1266-1271.
6. Critchley LA, Critchley JA. A meta-analysis of studies using bias and precision statistics to compare cardiac output measurement techniques. J Clin Monit Comput 1999;15:85-91.
7. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.
8. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med 2011;155:529-536.
9. Suehiro K, Joosten A, Murphy LS, et al. Accuracy and precision of minimally-invasive cardiac output monitoring in children: a systematic review and meta-analysis. J Clin Monit Comput 2016;30:603-620.
10. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ 2003;327:557-560.
11. Phillips R, Paradisis M, Evans N, et al. Cardiac output measurement in preterm neonates: validation of USCOM against echocardiography. Australia Critical Care 2006.
12. Patel N, Dodsworth M, Mills JF. Cardiac output measurement in newborn infants using the ultrasonic cardiac output monitor: an assessment of agreement with conventional echocardiography, repeatability and new user experience. Arch Dis Child Fetal Neonatal Ed 2011;96:F206-211.
13. Zheng ML, Sun X, Zhong J, et al. [Clinical study of neonatal cardiac output measurement methods]. Zhonghua Er Ke Za Zhi 2013;51:58-63.
14. Dong HR, He SR, Zhuang J, et al. [Two methods used for evaluating cardiac output accuracy in early preterm infants with critical illness]. Zhonghua Shiyong Erke Linchuang Za Zhi 2015;30:105-109.
15. Fraga MV, Dysart KC, Rintoul N, et al. Cardiac Output Measurement Using the Ultrasonic Cardiac Output Monitor: A Validation Study in Newborn Infants. Neonatology 2019;116:260-268.
16. Singh Y, Villaescusa JU, da Cruz EM, et al. Recommendations for hemodynamic monitoring for critically ill children-expert consensus statement issued by the cardiovascular dynamics section of the European Society of Paediatric and Neonatal Intensive Care (ESPNIC). Crit Care 2020;24:620.
17. de Waal K, Kluckow M. Functional echocardiography; from physiology to treatment. Early Hum Dev 2010;86:149-154.
18. He SR, Zhang C, Liu YM, et al. Accuracy of the ultrasonic cardiac output monitor in healthy term neonates during postnatal circulatory adaptation. Chin Med J (Engl). 2011;124:2284-2289.
19. Meyer S, Todd D, Shadboldt B. Assessment of portable continuous wave Doppler ultrasound (ultrasonic cardiac output monitor) for cardiac output measurements in neonates. J Paediatr Child Health 2009;45:464-468.
20. Menif K, Ayari A, Louati A, Ibn Haj Hassine S, Bouziri A, Borgi A. Agreement of cardiac index measurements between ultrasonic cardiac output monitor and transthoracic echocardiography in neonates. Tunis Med 2024;102:565-570.
21. Doni D, Faraguna MC, Zannin E, et al. Hemodynamic evaluation in preterm infants using ultrasonic cardiac output monitor (USCOM). Eur J Pediatr 2024;183:2183-2192.
22. Liu YM, Zheng ML, Sun X, et al. The clinical value of ultrasonic cardiac output monitor in very-low birth-weight and extremely-low-birth-weight infants undergoing PDA ligation. Early Hum Dev 2022;165:105522.

23. Critchley LA, Peng ZY, Fok BS, Lee A, Phillips RA. Testing the reliability of a new ultrasonic cardiac output monitor, the USCOM, by using aortic flowprobes in anesthetized dogs. Anesth Analg 2005;100:748-753.
24. Doni D, Nucera S, Rigotti C, et al. Evaluation of hemodynamics in healthy term neonates using ultrasonic cardiac output monitor. Ital J Pediatr 2020;46:112.
25. Boyle M, Steel L, Flynn GM, et al. Assessment of the clinical utility of an ultrasonic monitor of cardiac output (the USCOM) and agreement with thermodilution measurement. Crit Care Resusc 2009;11:198-203.
26. Gunjan K, Modi M, Thakur A, Soni A, Saluja S. Echocardiographic characteristics in neonates with septic shock. Eur J Pediatr 2024;183:1849-1855.
27. Peček JR, Koželj M, Fister P. Longitudinal Strain vs. Conventional Echocardiographic Parameters in the First Week of Life in Healthy Term Newborns. Pediatr Cardiol 2024;45:32-39.
28. Odor PM, Bampoe S, Cecconi M. Cardiac Output Monitoring: Validation Studies-how Results Should be Presented. Curr Anesthesiol Rep 2017;7:410-415.
29. Montenij LJ, Buhre WF, Jansen JR, Kruitwagen CL, de Waal EE. Methodology of method comparison studies evaluating the validity of cardiac output monitors: a stepwise approach and checklist. Br J Anaesth 2016;116:750-758.
30. Berthelsen PG, Nilsson LB. Researcher bias and generalization of results in bias and limits of agreement analyses: a commentary based on the review of 50 Acta Anaesthesiologica Scandinavica papers using the Altman-Bland approach. Acta Anaesthesiol Scand 2006;50:1111-1113.
31. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-310.
32. Mantha S, Roizen MF, Fleisher LA, Thisted R, Foss J. Comparing methods of clinical measurement: reporting standards for bland and altman analysis. Anesth Analg 2000;90:593-602.
33. Montenij LJ, Buhre WF, de Jong SA, et al. Arterial pressure waveform analysis versus thermodilution cardiac output measurement during open abdominal aortic aneurysm repair: a prospective observational study. Eur J Anaesthesiol 2015;32:13-19.
34. Critchley LA, Yang XX, Lee A. Assessment of trending ability of cardiac output monitors by polar plot methodology. J Cardiothorac Vasc Anesth 2011;25:536-546.
35. Fremuth J, Kobr J, Sasek L, Pizingerova K, Zamboryova J, Sykora J. Ultrasound cardiac output monitoring in mechanically ventilated children. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 2021;165:428-434.
36. Peček J, Koželj M, Lenasi H, Fister P. Right Ventricular Function in Neonates During Early Postnatal Period: A Prospective Observational Study. Pediatr Cardiol 2022;43:1327-1337.