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Original Research

Journal of Intensive Care Medicine
1-11
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DOI: 10.1177/08850666261503571
journals.sagepub.com/home/jic
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Electrical Cardiometry for Non-Invasive Cardiac Output Monitoring in Neonatal and Pediatric Critical Care: A Bayesian Systematic Review and Meta-Analysis

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Abstract

Objectives: To evaluate the agreement between electrical cardiometry and established reference methods for cardiac output measurement in neonatal and pediatric critical care using Bayesian meta-analysis, while synthesizing evidence on stroke volume bias, prognostic associations, and hemodynamic-guided management.

Design: Systematic review and Bayesian hierarchical random-effects meta-analysis conducted according to PRISMA 2020 recommendations.

Setting: Neonatal and pediatric intensive care units, emergency care settings, and interhospital transport services.

Data Sources: MEDLINE via PubMed, Embase, Google Scholar, and ScienceDirect were searched from database inception through March 2026. Reference lists and forward citation tracking were additionally performed to identify eligible studies.

Measurements and Main Results: Six studies including 448 neonates and children met the eligibility criteria. Three method-comparison studies enrolled 223 participants, of which two studies comprising 193 participants and four datasets contributed to the primary Bayesian synthesis. The pooled posterior mean percentage error was 26.9% (95% credible interval [CrI], 24.3%–29.5%), with a 98.3% posterior probability that the true percentage error remained ≤30%. A secondary analysis showed a pooled stroke volume bias of 2.82 mL (95% CrI, 1.71-3.86) and a 99.5% posterior probability that the absolute bias remained <5 mL. Observational evidence associated lower cardiac output with longer mechanical ventilation, while a pilot randomized trial suggested that electrical cardiometry-guided management reduced fluid administration and accelerated vasoactive therapy initiation.

Conclusions: Pooled evidence indicated a high posterior probability of clinically acceptable agreement between electrical cardiometry and reference methods for cardiac output measurement. Its prognostic and therapeutic value should be confirmed in larger multicenter prospective studies.

Keywords

electrical cardiometry, cardiac output, pediatric critical care, hemodynamic monitoring, Bayesian meta-analysis

Introduction

Hemodynamic assessment is fundamental to the recognition and management of circulatory dysfunction in critically ill children.[1,2] Cardiac output, stroke volume, and vascular tone determine systemic oxygen delivery, yet clinical signs alone provide an incomplete and sometimes misleading representation of cardiovascular performance. Transthoracic echocardiography has therefore become a central bedside tool in pediatric critical care; however, it provides intermittent measurements, remains operator dependent, and requires appropriate acoustic windows

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and specialized expertise.[1] More invasive techniques, including pulmonary artery or transpulmonary thermodilution, are rarely used routinely in children because of technical complexity, vascular access limitations, and procedure-related risks.[3] These constraints have created a clinical need for non-invasive technologies capable of providing continuous and rapidly available hemodynamic information.

Electrical cardiometry (EC) is a noninvasive technology that estimates stroke volume and cardiac output from cardiac-cycle–related changes in thoracic electrical impedance. Electrical velocimetry (EV) refers to the underlying measurement principle, which interprets impedance changes associated with erythrocyte orientation and aortic blood flow during ventricular ejection.[4-6] Its algorithm interprets changes conventionally attributed to variations in erythrocyte orientation and aortic blood flow velocity, allowing continuous bedside estimation of cardiac output, cardiac index, stroke volume, systemic vascular resistance, and thoracic fluid content. The technology is easy to deploy and does not require intravascular catheterization or repeated acquisition by an experienced echocardiographer.[6] Nevertheless, its measurement performance may be influenced by body size, thoracic fluid and air content, mechanical ventilation, abnormal cardiac anatomy, and the precision of the comparator method.[7] Published pediatric studies have reported variable agreement between electrical cardiometry and echocardiographic or Doppler-based reference techniques, and the available evidence has been derived from heterogeneous populations that frequently include, congenital heart disease, perioperative cardiac patients, and clinically stable cohorts.[8-10] Consequently, the applicability of these findings to critically ill children without congenital heart disease remains uncertain.

Method-comparison research should determine not only the magnitude of average bias but also whether measurement disagreement remains within a clinically acceptable boundary. For cardiac output monitoring technologies, a percentage error of 30% has traditionally been used as a pragmatic criterion of acceptable agreement, although its interpretation depends on the precision of both the index and reference methods.[1] Conventional evidence syntheses have not directly quantified the probability that electrical cardiometry satisfies this threshold in pediatric critical illness, and the limited number and heterogeneity of available studies produce substantial uncertainty.

A Bayesian hierarchical framework is particularly suited to this setting because it estimates the full posterior distribution of agreement parameters and permits direct calculation of the probability that the pooled percentage error lies within a prespecified clinical boundary.[11,12] We therefore conducted a systematic review and Bayesian meta-analysis to evaluate agreement between electrical cardiometry and reference hemodynamic methods in critically ill children without congenital heart disease. The primary objective was to estimate the pooled percentage error and the posterior probability that it was 30% or lower; secondary objectives were to synthesize stroke-volume bias and summarize evidence concerning diagnostic performance, prognostic associations, and the clinical utility of electrical cardiometry-guided management.

Materials and Methods

Study Design and Reporting Standards

We conducted a systematic review and Bayesian meta-analysis to evaluate the agreement, diagnostic performance, prognostic value, and clinical utility of electrical cardiometry for hemodynamic assessment in critically ill pediatric patients without congenital heart disease. The target population included premature and term neonates, infants, children, and adolescents receiving care in neonatal or pediatric critical care and other acute care settings.

The review was designed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement. Methodological procedures were guided by the Cochrane Handbook for Systematic Reviews of Interventions and established recommendations for the synthesis of diagnostic, prognostic, and method-comparison evidence, as appropriate to the objectives and outcomes of this review.[13-15] The protocol was developed prospectively according to PROSPERO requirements before study selection, data extraction, and quantitative synthesis (PROSPERO 2026 CRD420261451014).

Eligibility Criteria

Studies enrolling critically ill pediatric patients from birth through 18 years of age were eligible, including premature and term neonates, infants, children, and adolescents admitted to neonatal or pediatric intensive care units, emergency departments, interhospital transport services, or other acute care settings.

Eligible index technologies included electrical cardiometry, electrical velocimetry, impedance cardiography, and related thoracic bioimpedance-based methods designed to estimate cardiac output or other hemodynamic variables. Comparator methods included transthoracic echocardiography, Doppler-based cardiac output assessment, ultrasonic cardiac output monitoring, thermodilution, magnetic resonance imaging, Fick-derived cardiac output measurements, and other clinically established reference methods.

Studies were eligible if they reported at least one outcome related to method agreement or clinical performance. Agreement outcomes included cardiac output, cardiac index, stroke volume, systemic vascular resistance, bias, limits of agreement, percentage error, mean percentage error, Bland–Altman statistics, reproducibility, reliability, or trending ability. Studies assessing diagnostic performance, prognostic associations, or the clinical effects of electrical cardiometry-guided management were also eligible.

Randomized controlled trials, prospective or retrospective cohort studies, cross-sectional studies, diagnostic accuracy studies, feasibility studies, prognostic investigations, and method-comparison studies were considered for inclusion. Studies exclusively enrolling patients with congenital heart disease, postcardiac surgery populations, or patients receiving

extracorporeal membrane oxygenation were excluded. Animal studies, case reports, editorials, narrative reviews, conference abstracts without sufficient quantitative data, and studies lacking extractable pediatric results were also excluded.

Search Strategy and Information Sources

A comprehensive systematic search was performed in MEDLINE via PubMed, Google scholar, Embase and Science Direct from database inception through March 2026, without restrictions on publication year. The search strategy combined controlled vocabulary and free-text terms related to electrical cardiometry, electrical velocimetry, impedance cardiography, thoracic bioimpedance, cardiac output, cardiac index, stroke volume, hemodynamic monitoring, neonatal critical care, and pediatric critical illness. Reference lists of eligible articles and relevant systematic reviews were manually screened, and forward citation tracking was performed to identify additional studies. The complete search strategy for each database is provided in Supplemental Material Appendix 1.

Study Selection

Two reviewers independently screened titles and abstracts against the predefined eligibility criterio (JFS, PR). Potentially eligible reports subsequently underwent independent full-text assessment. Reasons for exclusion at the full-text stage were documented.

Disagreements at either stage were resolved through discussion and consensus. When consensus could not initially be reached, the study was reassessed jointly using the prespecified eligibility criteria.

Data Extraction

Data were independently extracted using a standardized data collection form. Extracted variables included author, country, publication year, study design, clinical setting, eligibility criteria, population characteristics, gestational or chronological age, sample size, electrical cardiometry device, comparator method, measurement protocol, hemodynamic variables, agreement statistics, diagnostic performance indices, prognostic outcomes, therapeutic interventions, and patient-centered outcomes.

For method-comparison studies, extracted parameters included mean bias, standard deviation of the bias, 95% limits of agreement, percentage error, mean percentage error, correlation or reliability coefficients, and trending metrics when available. Percentage error and mean percentage error were analyzed on a common percentage scale because both represented proportional disagreement between the index and comparator methods as reported by the original studies.

When a study reported more than one eligible hemodynamic variable, comparator method, measurement condition, or clinically distinct subgroup, each comparison was extracted as a separate dataset. Comparisons originating from the same study were retained as statistically related observations and accounted for within the hierarchical modeling structure.

Studies that did not report sufficient agreement statistics for quantitative pooling were retained in the qualitative synthesis when they contributed relevant evidence regarding feasibility, diagnostic performance, prognosis, or clinical utility.

Risk of Bias Assessment

Risk of bias was evaluated independently by two reviewers using design-appropriate criteria. Method-comparison and diagnostic accuracy studies were assessed using a QUADAS-2–based framework adapted to evaluate patient selection, conduct and interpretation of the index test, reference method, flow and timing, and statistical analysis of agreement.[16] Particular attention was given to simultaneity of measurements, blinding, repeated measurements, handling of within-patient dependence, appropriateness of the comparator method.

Randomized controlled trials were assessed across domains related to randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. Observational studies evaluating prognosis or clinical utility were assessed for selection bias, measurement of exposures and outcomes, confounding, missing data, and selective reporting. Each domain was classified as having low, high, or unclear risk of bias. Disagreements were resolved through consensus.

Outcomes

The primary outcome was agreement between electrical cardiometry-derived hemodynamic measurements and established reference methods. Agreement was primarily quantified using percentage error (PE), the prespecified metric for evaluating clinical interchangeability, regardless of whether it was reported for cardiac output, cardiac index, or stroke volume. Clinical acceptability was defined a priori as a percentage error of $\leq$30%, consistent with the conventional criterion proposed for method-comparison studies of cardiac output monitoring.[17,18] This threshold was interpreted as a pragmatic benchmark for clinically acceptable agreement rather than definitive evidence of interchangeability, because the observed percentage error is influenced by the measurement precision of both the index and reference methods.

The principal Bayesian estimand was the posterior distribution of the pooled percentage error and the posterior probability that the true pooled percentage error was 30% or lower:

$$P(PE \leq 30\%)$$

A secondary agreement outcome was the pooled absolute bias in stroke volume. For this outcome, the prespecified Bayesian estimand was the posterior probability that the absolute pooled bias was less than 5 mL:

$$P(|Bias| < 5\,mL)$$

Additional secondary outcomes included hemodynamic variables derived from electrical cardiometry, including systemic vascular resistance, systemic vascular resistance index, and thoracic fluid content, as well as measures of device performance such as reproducibility, reliability, and trending ability. Diagnostic performance outcomes included the ability of electrical cardiometry-derived variables to identify fluid responsiveness, summarized using sensitivity, specificity, area under the receiver operating characteristic curve, and reported diagnostic thresholds. Prognostic and clinical utility outcomes included mortality, duration of mechanical ventilation, vasoactive support, fluid administration, fluid overload, organ dysfunction, intensive care unit length of stay, hospital length of stay, ventilator-free days, intensive care unit-free days, and hospital-free days.

Statistical Analysis

Study characteristics were summarized descriptively. Categorical variables were reported as frequencies and percentages, whereas continuous variables were summarized as means with standard deviations or medians with interquartile ranges, according to their distribution and the reporting format used in the original studies.

Because of the limited number of eligible studies, relatively small sample sizes, multiple datasets within individual studies, heterogeneous comparator methods, and variability in age groups and clinical settings, Bayesian hierarchical random-effects meta-analysis was prespecified as the primary quantitative framework. This approach was selected to model between-study heterogeneity, account for the hierarchical structure of datasets nested within studies, and directly estimate clinically interpretable posterior probabilities.

Percentage error and mean percentage error were synthesized on a common proportional-error scale. Cardiac output, cardiac index, and stroke volume datasets were eligible for inclusion in the primary agreement model when the original study reported a percentage-based measure of disagreement. Distinct comparator methods and clinically defined study groups were represented as separate datasets, while their common study origin was incorporated into the hierarchical model. Stroke volume bias, expressed in milliliters, was analyzed in a separate Bayesian hierarchical random-effects model and was not combined with percentage-based agreement outcomes.

Weakly informative prior distributions were used to limit undue prior influence while maintaining computational stability in the context of sparse evidence. Posterior distributions were estimated using Markov chain Monte Carlo simulation. Model convergence and sampling performance were evaluated using trace plots, effective sample sizes, and the Gelman–Rubin convergence statistic, with R-hat values close to 1.00 considered indicative of satisfactory convergence. Posterior means and corresponding 95% credible intervals were calculated for pooled agreement estimates. Unlike frequentist confidence intervals, credible intervals were interpreted as containing the parameter of interest with 95% posterior probability, conditional on the observed data and model assumptions.

The principal analysis estimated the pooled percentage error and:

$$P(PE \leq 30\%)$$

The secondary Bayesian analysis estimated pooled stroke volume bias and:

$$P(|Bias| < 5\,mL)$$

Posterior distributions were displayed graphically using interval plots and probability-density plots. The prespecified clinical thresholds were included in the figures to facilitate interpretation of the magnitude and uncertainty of the pooled estimates.

Between-study heterogeneity was modeled using study-level random effects and summarized through the posterior distribution of the heterogeneity parameter. Clinical and methodological heterogeneity were additionally examined according to age group, including premature neonates, term neonates and infants, and older children; clinical setting; comparator method; hemodynamic variable; and electrical cardiometry device, when the available data permitted meaningful assessment.

Sensitivity analyses evaluated the influence of alternative prior specifications, neonatal and premature populations, comparator methods, individual studies, and datasets originating from the same study. Qualitative findings from studies that could not be quantitatively pooled were synthesized by clinical domain, including method agreement, diagnostic accuracy, prognostic value, and clinical utility. The certainty of evidence was evaluated by outcome using an adaptation of the Grading of Recommendations Assessment, Development and Evaluation framework for diagnostic and method-comparison evidence. The assessment considered risk of bias, inconsistency, indirectness, imprecision, and potential publication bias.

All statistical analyses were performed using R software (R Foundation for Statistical Computing, Vienna, Austria). Bayesian models were fitted using the Stan probabilistic programming framework.

Results

Study Selection and Characteristics

The systematic search identified six studies that fulfilled the predefined eligibility criteria and were included in the qualitative synthesis, comprising 448 premature neonates, term neonates, infants, children, and adolescents across neonatal and pediatric intensive care units, emergency departments, and interhospital transport settings (Table 1).[19-24] The studies were published between 2014 and 2025 and included three prospective method-comparison or feasibility studies, one diagnostic accuracy study, one retrospective prognostic cohort, and one pilot randomized controlled trial (Figure 1).

Three studies evaluated agreement between electrical cardiometry (EC) and reference hemodynamic methods, collectively

Table 1. Characteristics of Studies Included in the Systematic Review and Bayesian Evidence Synthesis.

Study	Country	Year	Design	Population / Eligibility	Setting	N	Age	Device	Reference / Comparator	Main Outcome
Blohm	Germany	2014	Prospective single-center observational method-comparison study	Pediatric and neonatal ICU patients with normal biventricular anatomy; subgroups included organ transplantation, sepsis/organ failure, neurologic disease and preterm infants	PICU	72	2 days to 17 years	Aesculon EV	TTE using aortic VTI and M-mode	LVSV agreement; bias and MPE. EVVTI all cohort: bias 7.81%, MPE 26.16%; SEPSIS subgroup MPE 26.82%
Boet	France	2017	Prospective pragmatic feasibility cohort study	Hemodynamically stable neonates and infants undergoing interhospital transport; CHD other than PDA/PFO excluded; severe sepsis/septic shock excluded	Mobile ICU transport	30	<12 months; mean 29 days	ICON EC	Portable ultrasound	SV agreement/feasibility; SVEC-SVUS bias 2.7 ± 3.4 mL before/after and 3.0 ± 3.0 mL during transport
Chaiyakulsil	Thailand	2018	Prospective single-center observational method-comparison study	Critically ill children aged 1 month to 18 years; congenital heart disease and unstable hemodynamics excluded	PICU	121	Mean 4.9 years	ICON EV	TTE and USCOM	CO, CI and SV agreement. ICON versus TTE: CO bias 0.3 ± 1.9 L/min, PE 27.5%; CI bias 0.02 ± 2.2 L/min/m2, PE 28%; SV bias 3.5 ± 18 mL, PE 25.7%
Kadafi	Indonesia	2020	Cross-sectional diagnostic accuracy study	Critically ill children aged 1 month to 18 years with shock requiring fluid resuscitation and mechanical ventilation; CHD excluded	PICU/emergency room	45	Median 14 months	ICON EC	USCOM	Fluid responsiveness by SVV and SV change after fluid challenge. ICON sensitivity 58%, specificity 74%; SVV AUC 53%
Sumbel	United States	2020/2022	Retrospective PICU cohort/outcomes study	Critically ill children <21 years with respiratory failure and/or shock and available ICON data	PICU	61	Median 48 months	ICON EC	TTE within 6-h window when available	Low CO by EC did not correlate with TTE ($p = 0.9$); nadir and median CO predicted ventilator days
Moharana	India	2025	Pilot randomized controlled trial	Children 2 months to 18 years with pediatric septic shock unresolved after initial bolus; CHD and myocarditis excluded	PICU	119	2 months to 18 years	ICON-guided EC strategy	Clinical monitoring alone; both groups also received clinical/echo assessment	Initial 6-h resuscitation fluid lower with EC guidance: 22 ± 9.2 versus 30 ± 8.2 mL/kg; earlier vasoactive initiation; lower FO

Studies were categorized according to their contribution to the Bayesian synthesis. Primary agreement studies reported bias, limits of agreement, percentage error, or mean percentage error between electrical cardiometry/electrical velocimetry and a reference cardiac output method. Studies evaluating diagnostic performance, clinical outcomes, or prognostic associations were synthesized separately. Congenital heart disease was a predefined exclusion criterion for the primary quantitative synthesis. Abbreviations: CO, cardiac output; CI, cardiac index; SV, stroke volume; LVSV, left ventricular stroke volume; PE, percentage error; MPE, mean percentage error; EC, electrical cardiometry; EV, electrical velocimetry; PICU, pediatric intensive care unit; TTE, transthoracic echocardiography; VTI, velocity–time integral; USCOM, ultrasonic cardiac output monitor; CHD, congenital heart disease; FO, fluid overload.

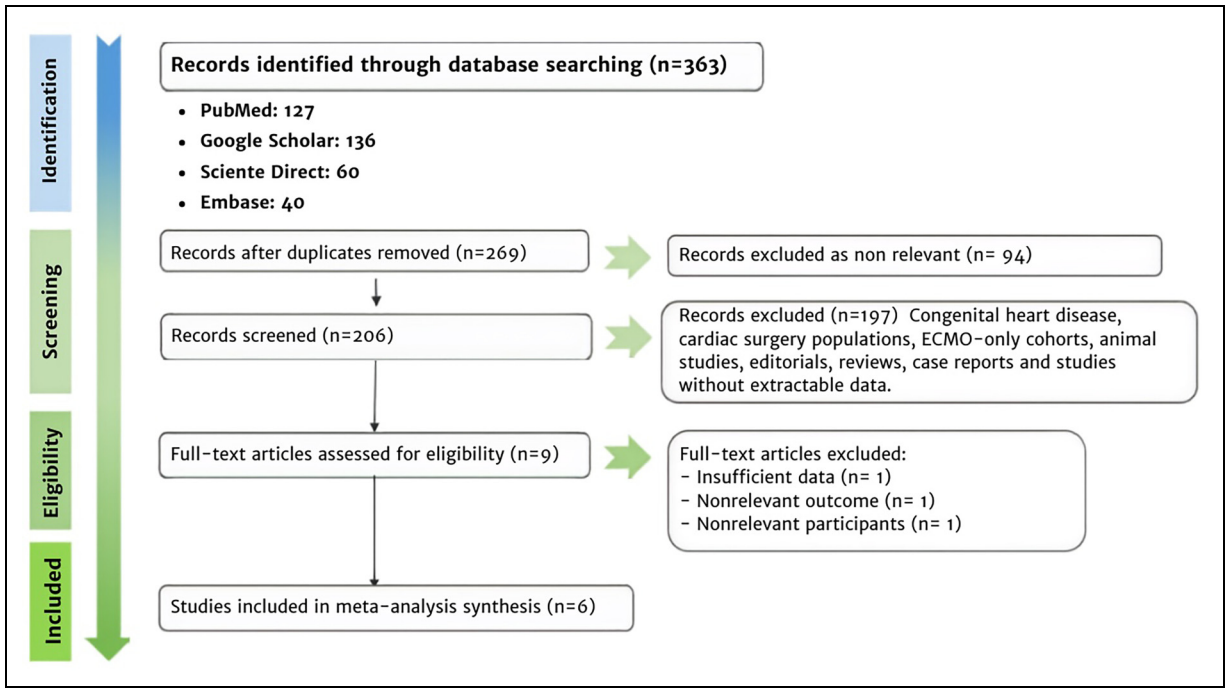

Figure 1. PRISMA flow diagram of study selection.

Table 2. Bayesian Pooled Estimates of Method Agreement Between Electrical Cardiometry and Reference Hemodynamic Methods.

Outcome	Studies Included	k Datasets	N Participants	Posterior Mean	95% CrI	Posterior Probability
Percentage error (primary agreement model)	Blohm 2014; Chanapai 2018	4	193	26.9%	24.3–29.5	P(PE ≤ 30%) = 98.3%
Stroke Volume Bias	Boet 2017; Chanapai 2018	3	151	2.82 mL	1.71–3.86	P(|bias|<5 mL) = 99.5%

CrI denotes Bayesian credible interval. Clinical acceptability was prespecified as PE ≤30%. Posterior probabilities represent the probability that the pooled estimate satisfied the corresponding clinical threshold.

enrolling 223 participants. These investigations included neonatal and pediatric intensive care populations as well as neonates and infants undergoing interhospital transport. Comparator methods consisted of transthoracic echocardiography using aortic velocity–time integral (VTI) or M-mode measurements, portable Doppler ultrasound, and ultrasonic cardiac output monitoring (USCOM) (Table 1).

The remaining three studies evaluated complementary clinical domains. One study assessed the diagnostic performance of EC-derived stroke volume variation (SVV) for identifying fluid responsiveness, one investigated prognostic associations between EC-derived cardiac output and clinical outcomes, and one examined an EC-guided hemodynamic management strategy in pediatric septic shock. Risk-of-bias assessments for individual studies are summarized in Figure S1 and Figure S2.

Bayesian Synthesis of Percentage Error

The primary Bayesian agreement analysis included four eligible datasets derived from two studies representing 193 participants.[19,20] These datasets reported percentage error (PE) or mean percentage error (MPE) between EC-derived measurements and echocardiographic or ultrasound-based reference methods (Table 2). The pooled posterior mean percentage error was 26.9%, with a 95% credible interval (CrI) of 24.3% to 29.5% (Figure 2). The posterior probability that the pooled percentage error remained at or below the prespecified threshold of 30% was 98.3%:

$$\mathbf{P(PE \leq 30\%) = 98.3\%}$$

The posterior distribution remained concentrated below the predefined threshold, indicating a high probability that the pooled proportional disagreement between EC-derived measurements and the included reference methods satisfied the criterion for clinically acceptable agreement (Figure 3).

Stroke Volume Bias

The secondary Bayesian synthesis included three stroke volume datasets derived encompassing 151 participants.[20,21] Boet et al[21]

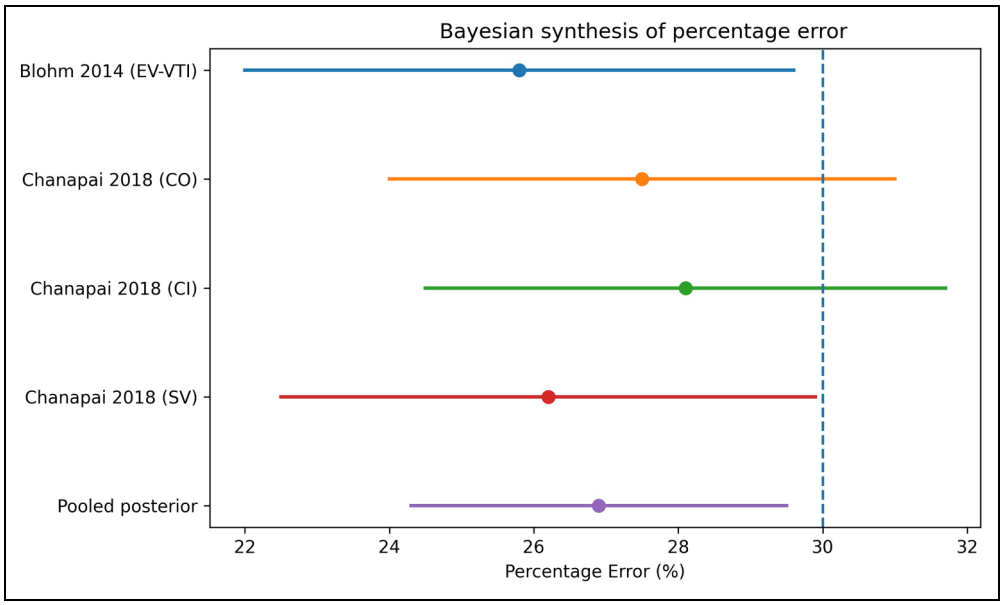

Figure 2. Bayesian pooled estimates of percentage error for agreement between electrical cardiometry and reference methods. Forest plot showing the posterior mean percentage error and corresponding 95% credible intervals (CrIs) for each independent dataset and the pooled Bayesian random-effects estimate. The vertical dashed line represents the prespecified threshold for clinically acceptable agreement (percentage error = 30%). The pooled posterior estimate remained below this threshold, supporting a high probability of clinically acceptable agreement between electrical cardiometry and the reference cardiac output measurement methods across the included studies.

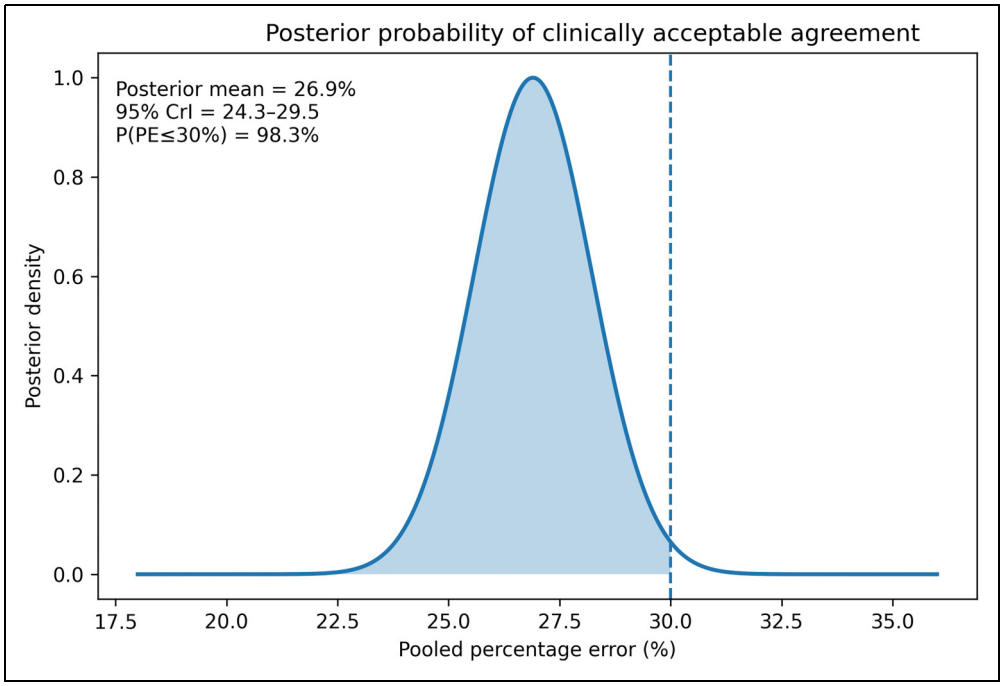

Figure 3. Posterior probability of clinically acceptable agreement between electrical cardiometry and reference methods. Posterior probability density of the pooled percentage error estimated using the Bayesian hierarchical random-effects model. The vertical dashed line indicates the prespecified threshold for clinically acceptable agreement (percentage error = 30%). The pooled posterior mean percentage error was 26.9% (95% credible interval [CrI], 24.3%–29.5%), with a 98.3% posterior probability that the true pooled percentage error remained ≤30%, supporting clinically acceptable agreement between electrical cardiometry and the reference cardiac output measurement methods.

contributed measurements obtained before or after transport and during transport, whereas Chaiyakulsi et al[20] contributed comparisons between electrical cardiometry and transthoracic echocardiography. The pooled posterior mean stroke volume bias was 2.82 mL, with a 95% CrI of 1.71 to 3.86 mL (Table 2 and Figure S2). The posterior probability that the absolute pooled bias remained below 5 mL was 99.5%:

$$\mathbf{P}(|\mathbf{Bias}| < \mathbf{5\ mL}) = \mathbf{99.5}\%$$

The pooled estimate indicated a small positive systematic difference between electrical cardiometry-derived and reference stroke volume measurements. However, a small mean bias alone does not establish narrow limits of agreement or individual-level measurement interchangeability (Figure S3).

Diagnostic Accuracy for Fluid Responsiveness

In a prospective diagnostic accuracy study including 45 mechanically ventilated children with shock undergoing fluid challenge, Kadafi et al evaluated the ability of EC-derived stroke volume variation to identify fluid responsiveness.

Electrical cardiometry demonstrated a sensitivity of 58%, specificity of 74%, and an area under the receiver operating characteristic curve (AUC) of 0.53 (95% CI, 0.36-0.70). The reported optimal SVV threshold was 16.5%, corresponding to a sensitivity of 54% and specificity of 58%. These findings indicate limited discriminative performance of EC-derived stroke volume variation when used as a standalone predictor of fluid responsiveness in heterogeneous pediatric shock populations.

Prognostic Associations

In a retrospective cohort including 61 critically ill children with acute respiratory failure and/or shock, Sumbel et al[22] analyzed 327 electrical cardiometry recordings obtained during pediatric intensive care admission. Lower nadir and median cardiac output measurements were associated with longer duration of mechanical ventilation ($p = 0.05$ and $p = 0.01$, respectively). In addition, nadir cardiac output demonstrated an inverse correlation with peak inotrope score. However, electrical cardiometry-defined low cardiac output was not associated with depressed ventricular function identified by transthoracic echocardiography among patients with paired measurements. Because these findings originated from a single retrospective cohort and outcome definitions differed substantially from those of the agreement studies, quantitative pooling was not performed.

Clinical Utility of Electrical Cardiometry-Guided Management

In a pilot randomized controlled trial including 119 children with pediatric septic shock, Moharana et al compared EC-guided hemodynamic management integrated with clinical assessment and echocardiography with standard clinical monitoring.[23]

The EC-guided strategy was associated with a lower volume of resuscitation fluid administered during the first six hours (22 ± 9.2 vs 30 ± 8.2 mL/kg), corresponding to a mean difference of −7.9 mL/kg (95% CI, −11.1 to −4.8). Total fluid administration during the first 24 h was likewise reduced (79.8 ± 18.7 vs 91.0 ± 16.4 mL/kg; mean difference −11.2 mL/kg, 95% CI, −17.5 to −4.8).

Vasoactive therapy was initiated earlier in the EC-guided group (37.0 ± 10.1 vs 47.3 ± 12.4 min; mean difference −10.3 min), and fluid overload occurred less frequently during follow-up. No significant differences were observed in time to shock resolution, mortality, ventilator-free days, intensive care unit-free days, or hospital-free days.

Evidence Synthesis Across Clinical Domains

The evidence map demonstrated that half of the included studies focused primarily on method agreement, whereas the remaining investigations evaluated diagnostic accuracy, prognostic performance, and clinical Utility (Figure S2).

The quantitative synthesis showed a pooled posterior percentage error of 26.9%, with a 98.3% posterior probability of remaining at or below the predefined clinical threshold of 30%. Likewise, pooled stroke volume bias was small (2.82 mL), with a 99.5% posterior probability that the absolute bias remained below 5 mL. Evidence beyond method agreement was more limited and derived from individual studies. Electrical cardiometry-derived stroke volume variation showed poor discrimination for predicting fluid responsiveness, whereas observational and randomized evidence suggested potential value for continuous risk stratification and optimization of fluid and vasoactive therapy. These findings were synthesized narratively because of differences in study design, patient populations, and outcome definitions.

Overall, the available evidence indicates that electrical cardiometry provides clinically acceptable agreement with established reference methods for estimating cardiac output and stroke volume across neonatal and pediatric critical care settings, while emerging evidence suggests potential applications in hemodynamic-guided management that warrant confirmation in larger prospective studies.

Discussion

In this Bayesian systematic review and meta-analysis, pooled evidence indicated a high posterior probability that electrical cardiometry achieved clinically acceptable agreement with established reference methods for non-invasive cardiac output assessment across neonatal and pediatric critical care populations. The pooled posterior percentage error was 26.9% (95% CrI, 24.3-29.5), with a 98.3% posterior probability that the true pooled percentage error remained at or below the prespecified threshold of 30%. Similarly, the pooled stroke volume bias was small at 2.82 mL (95% CrI, 1.71-3.86), with a 99.5%

posterior probability that the absolute bias remained below 5 mL. Together, these findings support a high degree of confidence that electrical cardiometry provides measurements within prespecified boundaries of clinically acceptable agreement when compared with the reference techniques used in the included studies.

An important contribution of this review is the integration of evidence across the spectrum of neonatal and pediatric critical illness rather than within a single clinical scenario. Previous investigations have frequently evaluated electrical cardiometry in highly selected populations, including neonates, postoperative cardiac surgery patients, children with congenital heart disease, or narrow validation cohorts.[4,5,7] By synthesizing evidence from premature neonates through adolescents across intensive care, emergency, transport, and septic shock settings, the present review provides a broader assessment of the technology under the heterogeneous clinical conditions in which bedside hemodynamic monitoring is required.

The principal methodological contribution of this study lies in the Bayesian framework. Conventional meta-analyses generally summarize pooled estimates and associated uncertainty, whereas Bayesian inference allows direct estimation of the probability that a monitoring technology satisfies a clinically relevant performance threshold. Rather than focusing on whether the pooled estimate differs from an arbitrary null value, the present analysis quantified the probability that electrical cardiometry remained within the prespecified criterion for clinically acceptable agreement. This interpretation is directly aligned with clinical decision-making, in which the relevant question is the likelihood that a monitoring method performs within an acceptable range under conditions of uncertainty.

The observed agreement is physiologically plausible given the principles underlying electrical cardiometry. The technique estimates stroke volume and cardiac output from cardiac-cycle–related changes in thoracic electrical bioimpedance during ventricular ejection.[2,5] Signal acquisition may be influenced by factors commonly encountered during critical illness, including mechanical ventilation, pleural effusions, pulmonary edema, changes in thoracic fluid content, body size, and marked alterations in vascular tone. Despite this physiological and clinical heterogeneity, the posterior distribution of pooled percentage error remained concentrated below the predefined threshold. This finding suggests that these factors may introduce variability without necessarily precluding clinically interpretable serial measurements across diverse neonatal and pediatric settings.

The review also indicates that the potential clinical value of electrical cardiometry may extend beyond method agreement. In the included pilot randomized trial, incorporation of electrical cardiometry into a structured hemodynamic management protocol was associated with lower resuscitation fluid administration, earlier initiation of vasoactive therapy, and less fluid overload, without differences in shock resolution, mortality, or other patient-centered outcomes.[23] These findings should be interpreted cautiously because they arise from a single pilot trial. Nevertheless, they suggest that continuous non-invasive hemodynamic information may facilitate more individualized resuscitation strategies when integrated with clinical and echocardiographic assessment.

Observational evidence similarly suggested that electrical cardiometry-derived cardiac output may provide clinically relevant prognostic information.[20-22,24] Lower nadir and median cardiac output values were associated with longer duration of mechanical ventilation, and nadir cardiac output was inversely correlated with peak inotrope requirements. These associations do not establish causality and may be influenced by disease severity and treatment intensity. However, they support the possibility that serial electrical cardiometry measurements capture meaningful changes in cardiovascular performance during critical illness.

In contrast, electrical cardiometry-derived stroke volume variation had limited discriminatory performance for predicting fluid responsiveness. The only eligible diagnostic accuracy study reported an area under the receiver operating characteristic curve of 0.53, indicating that stroke volume variation alone did not reliably distinguish responders from nonresponders. This limitation likely reflects the complex physiological determinants of dynamic preload indices rather than the performance of electrical cardiometry as a whole. Stroke volume variation is influenced by controlled mechanical ventilation, tidal volume, cardiac rhythm, chest wall mechanics, right ventricular function, and cardiopulmonary interactions. Accordingly, electrical cardiometry-derived dynamic indices should be interpreted within a multimodal hemodynamic assessment rather than used as isolated decision rules for fluid administration.

Another important consideration is the nature of the comparator methods. The studies included in this review primarily used transthoracic echocardiography, Doppler-based techniques, portable ultrasound, or ultrasonic cardiac output monitoring rather than invasive thermodilution. These methods are clinically established but possess their own measurement error, operator dependence, and reproducibility limitations. Therefore, the pooled estimates should be interpreted as agreement with accepted clinical reference methods rather than as evidence of absolute measurement accuracy. This distinction is particularly relevant when applying a percentage-error threshold originally developed for comparisons involving reference methods with different precision characteristics.

From a global health perspective, the findings may be relevant in settings where access to invasive hemodynamic monitoring or repeated functional echocardiography is limited by equipment, staffing, or operator expertise.[1,2] Electrical cardiometry is non-invasive, portable, rapidly deployable, and capable of continuous monitoring. It should not be considered a substitute for functional echocardiography, which provides structural and diagnostic information unavailable from bioimpedance-based monitoring. Rather, electrical cardiometry may serve as an adjunctive bedside modality that extends serial cardiovascular assessment between formal echocardiographic examinations and during resuscitation, transport, and stabilization.

Several limitations should be acknowledged. First, only six studies met the eligibility criteria, and quantitative synthesis

was possible for a subset of agreement outcomes. Second, substantial clinical and methodological heterogeneity existed across age groups, clinical settings, comparator methods, measurement protocols, and reported agreement metrics. Third, most studies were single-center investigations with modest sample sizes, limiting the precision and generalizability of individual estimates. Fourth, multiple datasets originated from the same studies, creating potential within-study dependence despite the use of hierarchical modeling. Fifth, evidence concerning diagnostic accuracy, prognostic value, and clinical utility was derived from individual studies and could not be quantitatively synthesized because of differences in design and outcome definitions. Finally, Bayesian posterior estimates remain conditional on the included evidence, model structure, and prior assumptions and should therefore be updated as larger and methodologically rigorous studies become available.

Conclusion

In this Bayesian systematic review and meta-analysis, pooled evidence indicated a high posterior probability that electrical cardiometry achieved clinically acceptable agreement with established reference methods for cardiac output assessment across neonatal and pediatric critical care populations. The posterior probability that pooled percentage error remained at or below 30% was 98.3%, while the probability that absolute pooled stroke volume bias remained below 5 mL was 99.5%. These findings support electrical cardiometry as an adjunctive, non-invasive modality for serial estimation of cardiac output and stroke volume. Further multicenter prospective studies should determine whether its integration into protocolized hemodynamic management improves therapeutic decision-making and patient-centered outcomes.

Acknowledgments

To all the physicians, nurses, therapists, and professionals dedicated to saving critically ill children's lives within the Latin American Society of Pediatric Intensive Care (SLACIP).

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Human Ethics and Consent to Participate Declarations

The authors affirm that this manuscript is original, has not been published previously, and is not under consideration for publication elsewhere. All figures, tables, and Supplemental materials are original or reproduced with appropriate permission when applicable. As this study is a systematic review and meta-analysis of previously published data, institutional ethics committee approval and informed consent were not required.

Consent for Publication

Not applicable.

Authors' Contributions

All authors made substantial contributions to the conception and design of the study. JFS conceived the study, developed the review protocol, supervised the systematic review, performed the Bayesian meta-analysis, interpreted the data, and drafted the initial manuscript. All authors participated in study selection, data extraction, critical interpretation of the findings, and revision of the manuscript for important intellectual content. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the study are appropriately investigated and resolved.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by Universidad de La Sabana (Grant MEDESP-85-2025), under the approved research protocol "*Electrical Cardiometry for Non-Invasive Hemodynamic Assessment in Critically Ill Children Without Congenital Heart Disease: A Systematic Review and Bayesian Meta-Analysis of Method Agreement*". The funding source had no role in study design, data collection, analysis, interpretation, manuscript writing, or the decision to submit for publication. All authors had full access to the data and take responsibility for its integrity and the accuracy of the analysis.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Availability of Supporting Data

Not applicable.

Supplemental Material

Supplemental material for this article is available online.

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