Paediatrica Indonesiana

p-ISSN 0030-9311; e-ISSN 2338-476X; Vol.65, No.6 (2025). p.480-7; DOI: https://doi.org/10.14238/pi65.6.2025.480-7

Original Article

Diagnostic performance of electrical cardiometry (*ICON*) parameters in predicting fluid responsiveness in critically ill pediatric patients

Kurniawan Taufiq Kadafi[1], Wanda Rizki Dzakiyah Sholikhah[2], Muhammad Reva Aditya[2], Saptadi Yuliarto[1], Charity Monica[1], Abdul Latief[3], Antonius Hocky Pudjiadi[4]

Abstract

Background Fluid resuscitation with appropriate and adequate amounts is very important in treating critically ill children, so reliable hemodynamic monitoring methods are needed to prevent fluid overload. Contractility index (ICON) is a novel, non-invasive index of left ventricular (LV) function, and contractility related to the electrical cardiometry device (*ICON*®). The *ICON*® offers a non-invasive hemodynamic monitoring method to assess volume status, but its validity in predicting fluid response in the Indonesian pediatric population remains unknown.

Objective To determine the diagnostic performance of ICON-derived parameters, especially change of cardiac output (ΔCO) and change in contractility index (ΔICON), in predicting fluid response, using change of stroke volume (ΔSV) as a reference standard.

Methods A cross-sectional study was conducted in pediatric emergency and intensive care settings. Children aged 1 month to 18 years requiring fluid resuscitation were included. Hemodynamic parameters were measured using *ICON*® before and after a 10 mL/kg fluid bolus of crystalloid. Fluid responsiveness was defined as a >10% increase in ΔSV. Changes in parameters were analyzed using paired statistical tests. The ROC analysis was used to assess the diagnostic accuracy of CO and ICON.

Results Sixty-three subjects were analyzed. Significant median changes were observed after fluid bolus administration based on pre- and post-bolus comparison in change of heart rate (ΔHR: -8 bpm, P<0.001), change of systolic blood pressure (ΔSBP: +3 mmHg, P=0.042), change of diastolic blood pressure (ΔDBP: +2 mmHg, P=0.012), change of mean arterial pressure (ΔMAP: +0.67 mmHg, P=0.009). The ROC analysis showed that CO had the highest AUC (0.878), with a cut-off of 5.35%, sensitivity of 78.3%, and specificity of 87.2%. The ICON showed moderate accuracy (AUC 0.757), with a 0.45% cut-off, 69.6% sensitivity, and 71.8% specificity.

Conclusion Electrical cardiometry (ICON®) demonstrated measurable changes in objective hemodynamic parameters following fluid bolus administration in critically ill children. Among ICON-derived parameters, a 5.35% increase in CO showed the best predictive performance for fluid responsiveness, while ICON showed moderate diagnostic value. These findings support the clinical utility of electrical cardiometry as a non-invasive tool to guide volume management in pediatric critical care. **[Paediatr Indones. 2025;65:480-7; DOI: https://doi.org/10.14238/pi65.6.2025.480-7].**

Keywords: *electrical cardiometry; fluid responsiveness; stroke volume; ICON®; critical illness; pediatric intensive care*

Optimal fluid management is one of the most critical components during the early stabilization phase in children experiencing shock. Administration of fluid boluses remains the first-line intervention in children with hemodynamic instability to restore effective circulating volume and improve tissue perfusion. However, both under-resuscitation and

From the Department of Pediatrics, Dr. Saiful Anwar General Hospital/ Universitas Brawijaya,[1] Faculty of Medicine, Universitas Brawijaya,[2] Malang, East Java; Pediatric Intensive and Critical Care Working Group, Indonesian Pediatric Society,[3] and Departement of Pediatrics, Division of Pediatric Intensive and Critical Care, Dr. Cipto Mangunkusumo Hospital/ Universitas Indonesia,[4] Jakarta, Indonesia.

Corresponding author: Wanda Rizki Dzakiyah Sholikhah. Faculty of Medicine, Universitas Brawijaya. Jalan Belakang RSU No.6, Malang, East Java, Indonesia. Email: wandaar269@gmail.com.

Submitted June 9, 2025. Accepted December 26, 2025.

fluid overload have been independently associated with adverse outcomes such as prolonged mechanical ventilation, worsening oxygenation, and increased mortality.[1] This balance highlights the importance of accurate, real-time assessment tools to guide volume administration in children.

Traditionally, clinicians have relied on static hemodynamic indicators, including traditional markers including measures such as heart rate, arterial systolic pressure, and central venous pressure, to determine the need for fluid administration. However, these indicators are widely considered to be insufficiently accurate for assessing volume responsiveness, especially in the pediatric population, who often maintain perfusion through compensatory mechanisms even in the face of hypovolemia.[2,3] Invasive methods such as thermodilution via pulmonary artery catheterization or arterial pressure waveform analysis can offer more precise assessments, but these techniques are often technically difficult, carry risks, and may not be feasible or appropriate in pediatric settings.[4,5] Therefore, a non-invasive hemodynamic monitoring method that can be carried out quickly, is valid and has high reliability, is needed.

Over the past decade, there has been growing utilization of non-invasive techniques for monitoring hemodynamics in pediatric emergency and intensive care settings. One such modality is electrical cardiometry (*ICON®*), which has emerged as a potentially valuable approach. This technique estimates stroke volume (SV), cardiac output (CO), and a contractility-related index known as the ICON through continuous analysis of thoracic bioimpedance. It allows for continuous, non-invasive assessment and is easy to operate at the bedside. Several validation studies have shown that *ICON®* correlates reasonably well with echocardiography and other established modalities in both term neonates and children.[6,7] Despite its potential, the role of *ICON®* in predicting fluid responsiveness, defined as a significant increase in stroke volume following fluid administration, has not been thoroughly explored in Indonesian pediatric populations.

According to the Frank-Starling principle, an increase in stroke volume (ΔSV) of ≥10% following fluid administration is commonly used to define fluid responsiveness.[8] Although transthoracic echocardiography (TTE) is considered the gold standard for stroke volume measurement, its routine application in acute pediatric settings is limited by operator dependency and availability. Therefore, many clinical studies have adopted ΔSV measured by validated non-invasive devices (e.g., USCOM) as a practical reference. In this study, ΔSV (≥10%) was used as the reference standard for fluid responsiveness. fluid responsive when stroke volume (ΔSV) increases by 10% or more after fluid administration, a threshold supported by the Frank-Starling principle.[8] While several studies have evaluated dynamic predictors such as SV variation or passive leg raise tests in adults, pediatric-specific data remain limited. In particular, it is unclear whether ICON®-derived parameters such as CO or ICON can reliably predict fluid responsiveness in children receiving fluid boluses in the intensive care setting. Therefore, the objective of this study was to evaluate the diagnostic performance of two ICON®-derived parameters, CO and ICON, for identifying fluid responsiveness in severely ill children, using a ≥10% rise in stroke volume (ΔSV) as the reference standard.

Methods

This observational cross-sectional study was carried out in the Pediatric Emergency and Intensive Care Units of Cipto Mangunkusumo General Hospital, a tertiary referral hospital in Jakarta, Indonesia. Critically ill pediatric patients, aged 1 month to 18 years, who were admitted between March and September 2017 with hemodynamic problems or shock necessitating fluid resuscitation and those receiving mechanical ventilation, were screened for eligibility and enrolled the study. Children who had kidney failure, congestive heart failure, congenital heart disease, arrhythmia (abnormal heart rhythm), and contraindications to fluid bolus therapy were excluded from this study. Patients were consecutively recruited until the sample size was reached within the study period.[8]

All articipants received a standardized 10 mL/kg crystalloid fluid bolus administered over 15-30 minutes. Hemodynamic parameters, including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), SV, CO, and ICON, were non-invasively measured

using the ICON® device before and immediately after fluid administration.

The ICON® monitor functions by positioning four surface electrodes on the left side of the body, four surface electrodes placed at the left forehead, the base of the neck, the left thorax, and the left thigh (**Figure 1**). Prior to data collection, signal strength was verified to ensure at least 100% signal quality. The upper electrode pair transmits a low-amplitude, high-frequency alternating current that is harmless to the patient. The device detects changes in thoracic electrical bioimpedance resulting from pulsatile red blood cell movement during the cardiac cycle. These bioimpedance changes are captured between the paired sensors. The *ICON®* system uses a complex proprietary algorithm to calculate beat-to-beat hemodynamic parameters such as stroke volume and cardiac output continuously and non-invasively.

Fluid responsiveness was defined as a ≥ 10% increase in stroke volume (ΔSV), consistent with the Frank-Starling principle.[11] Changes in hemodynamic parameters were analyzed using paired statistical tests (e.g., Wilcoxon signed-rank test for non-normally distributed data). Receiver operating characteristic (ROC) curve analysis was performed to assess the diagnostic accuracy of CO (percent change in cardiac output) and ICON (change in contractility index), with calculation of area under the curve (AUC), optimal cut-off values, sensitivity, and specificity using the Youden index.

All participants, parents, or guardians provided written consent, and the study was approved by the Faculty of Medicine, University of Indonesia, and the Dr. Cipto Mangunkusumo Human Rights Committee for research involving humans. We used secondary data from a previous cross-sectional study that evaluated fluid responsiveness in critically ill children by comparing *ICON®* with *USCOM®*, a well-validated non-invasive device commonly used as a reference for stroke volume measurement.8 Data were analyzed using SPSS software, with statistical significance set at $P<0.05$.

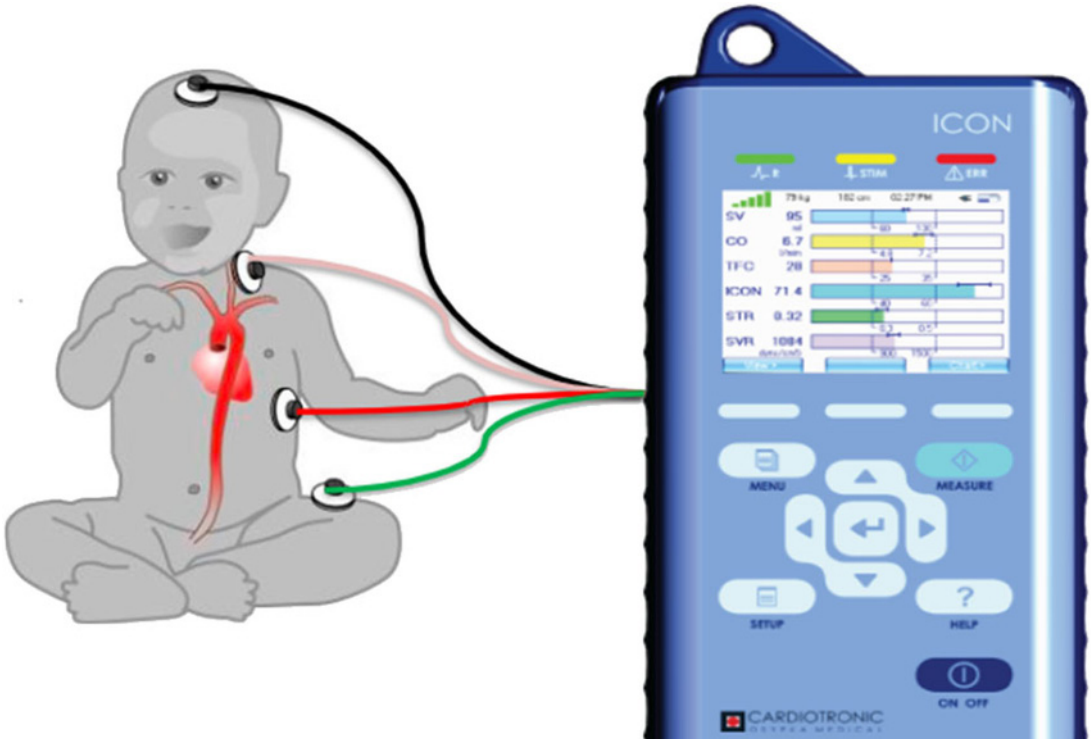

Figure 1. Illustration of sensor placement for the *ICON®* monitor. The first electrode is positioned on the forehead, the second at the left base of the neck, the third on the left side of the chest near the xiphoid level, and the fourth on the left thigh. (Adapted from the *ICON®* user manual with permission from *Markus Osypka*, Osypka Medical Inc., Germany.)

Results

This study included 62 pediatric patients who met the eligibility criteria and were recruited as participants. The participants had a median age of 12.5 months, ranging from 1 to 168 months, with a slightly higher proportion of females (56.5%) compared to males (43.5%). The median body weight was recorded at 7.7 kg, with values ranging between 3 and 45 kilograms, with a median body surface area recorded at 0.4 (range 0.2-1.4) m^2. For those who underwent mechanical ventilation, the median tidal volume administered was 7 (range 5-10) mL/kg of body weight. The majority of subjects (66.1%) required mechanical ventilation, whereas 33.9% were not ventilated. Among the ventilated group, 65.8% received pressure-controlled mandatory ventilation (P-CMV), 29.3% were managed with pressure-synchronized intermittent mandatory ventilation (P-SIMV), and 4.9% received pressure support-continuous positive airway pressure (PS-CPAP). Among non-ventilated patients, only 28.5% responded to fluid resuscitation, while 71.4% did not. In the P-CMV group, 37.1% showed a positive fluid response, and 62.9% did not. In contrast, 41.7% of P-SIMV patients responded to fluids, while 58.3% did not. All patients in the PS-CPAP group (2 patients) responded to fluid challenge. Most patients received fluid boluses for hypovolemic shock (71%), while the remainder had septic shock (29%). The most common underlying diagnoses were diarrhea (30.6%), postsurgical states (22.6%), and encephalitis or neurological disorders (19.4%). Other diagnoses included respiratory disorders (12.9%), tetanus (4.8%), sepsis (3.2%), fulminant hepatitis (3.2%), and acute kidney injury (3.2%) (**Table 1**).

Following fluid administration of 10 mL/kg BW, several clinical and hemodynamic parameters showed statistically significant changes. There was a notable decrease in heart rate, with a median change of -8 (range -45 to +12) bpm ($P<0.001$). Systolic blood pressure increased by a median of +3 (-27 to +63) mmHg ($P=0.042$), diastolic pressure increased by +2 (-22 to +41) mmHg ($P=0.012$), and MAP showed a median increase of +0.67 (-19.33 to +36.33) mmHg ($P=0.009$) (**Table 2**).

To evaluate the diagnostic performance of electrical cardiometry-derived parameters, ROC curve analysis was conducted using fluid responsiveness defined as an increase in stroke volume (ΔSV) ≥10% as the reference standard. The percent change in ΔCO demonstrated strong discriminative ability to identify responders, with AUC of 0.878, a cut-off value of 5.35%, sensitivity of 78.3%, and specificity of 87.2%. In addition, the percent change in ICON showed moderate diagnostic accuracy, with an AUC of 0.757, a cut-off of 0.45%, sensitivity of 69.6%, and specificity of 71.8% (**Table 3** and **Figure 2**).

Discussion

This study demonstrates the utility of electrical cardiometry (*ICON®*) as a valuable non-invasive tool for assessing fluid responsiveness in critically ill pediatric patients. The CO (percent change in cardiac output) was the most accurate predictor of fluid responsiveness, with an AUC of 0.878, sensitivity of 78.3%, and specificity of 87.2%, at a cutoff of 5.35%. Change in the index of contractility (ICON) showed moderate diagnostic performance (AUC 0.757), with a sensitivity of 69.6% and specificity of 71.8%, at a 0.45% cut-off. These findings reinforce the clinical applicability of ICON as a bedside monitoring device to guide fluid resuscitation in pediatric intensive care contexts.[7,9] The *ICON®* operates based on electrical bioimpedance across the thorax, detected through electrodes positioned at the forehead, neck, thorax, and thigh, which capture changes in erythrocyte alignment during cardiac cycles. During systole, erythrocytes align with blood flow, reducing thoracic impedance and increasing electrical conductivity, whereas during diastole, random orientation increases resistance. These changes are translated into stroke volume and CO in real time.[10] This continuous, beat-to-beat analysis enables dynamic monitoring of cardiovascular status without the inherent risks of invasive methods - an advantage particularly important in pediatric care, where patient vulnerability often limits the feasibility of invasive monitoring techniques.[7,11]

Electrical cardiometry (*ICON®*) functions through the application of four surface electrodes: with electrode placement involving four sensors placed at the left forehead, the base of the neck, the left thorax, and the left thigh. These electrodes continuously monitor thoracic electrical conductivity

Table 1. Baseline characteristics of study subjects

Characteristics	(N=62)
Median age (range), months	12.5 (1-168)
Gender, n (%)	
Male	27 (43.5)
Female	35 (56.5)
Median body weight (range), kg	7.7 (3-45)
Median body surface area (range), m²	0.4 (0.2-1.4)
Median tidal volume (range), mL/kg BW*	7 (5-10)
Mode of mechanical ventilation, n (%)	
Mechanical ventilation	41 (66.1)
No mechanical ventilation	21 (33.9)
Type of mechanical ventilation, n (%)	
P-CMV	27 (65.8)
P-SIMV	12 (29.3)
PS-CPAP	2 (4.9)
Mode of mechanical ventilation, n (%)	
Responded to fluid resuscitation	6 (28.5)
Not respond	15 (71.4)
Mode of mechanical ventilation: P-CMV, n (%)	
Responded to fluid resuscitation	10 (37.1)
Not respond	17 (62.9)
Mode of mechanical ventilation: P-SIMV, n (%)	
Responded to fluid resuscitation	5 (41.7)
Not respond	7 (58.3)
Mode of mechanical ventilation: PS-CPAP, n (%)	
Responded to fluid resuscitation	62 (100)
Not respond	0 (0)
Indication for fluid challenge, n (%)	
Hypovolemic shock	44 (71.0)
Septic shock	18 (29.0)
Underlying diseases and disorders, n (%)	
Tetanus	3 (4.8)
Respiratory disorder	8 (12.9)
Diarrhea	19 (30.6)
Encephalitis/neurological	12 (19.4)
Sepsis	2 (3.2)
Fulminant hepatitis	2 (3.2)
Postsurgery	14 (22.6)
Acute kidney injury	2 (3.2)

P-CMV=pressure-control mandatory ventilation; P-SIMV=pressure-synchronized intermittent mandatory ventilation; PS-CPAP=pressure support-continuous positive airway pressure; *only measured in ventilated patients

by delivering a low-intensity, high-frequency electrical current through the thoracic cavity. The system detects impedance changes that occur due to physiological factors influencing blood flow dynamics. Specifically, *ICON®* measures conductivity variations that correspond to the directional arrangement of erythrocytes in the aorta during different phases of the heartbeat. In systole, these cells orient themselves along the flow of blood, enhancing conductivity and lowering thoracic impedance.[17] In contrast, during diastole, their orientation becomes disorganized, which increases resistance to current flow and reduces conductivity. These changes in thoracic bioimpedance are processed by a proprietary algorithm, allowing real-time assessment of hemodynamic parameters such as stroke volume and cardiac output.[10,11]

The significant post-fluid bolus changes in hemodynamic parameters, particularly the decrease in heart rate (ΔHR: -8 bpm, $P<0.001$) align with the Frank-Starling mechanism, in which fluid

Table 2. Pre- and post-bolus comparison

Clinical parameter of shock	Median (range)	P value
ΔHeart rate, bpm	-8 (-45 - 12)	<0.001
ΔSystolic blood pressure, mmHg	+3 (-27 - 63)	0.042
ΔDiastolic blood pressure, mmHg	+2 (-22 - 41)	0.012
ΔMean arterial pressure, mmHg	+0.67 (-19.33 - -36.33)	0.009

Table 3. ROC analysis results for CO and ICON

Variables	AUC	Cut-off (%)	Sensitivity (%)	Specificity (%)
ΔCO	0.878	5.35	78.3	87.2
ΔICON	0.757	0.45	69.6	71.8

ΔCO=percent change in cardiac output before and after fluid bolus; ΔICON=percent change in ICON index (myocardial contractility) before and after fluid bolus

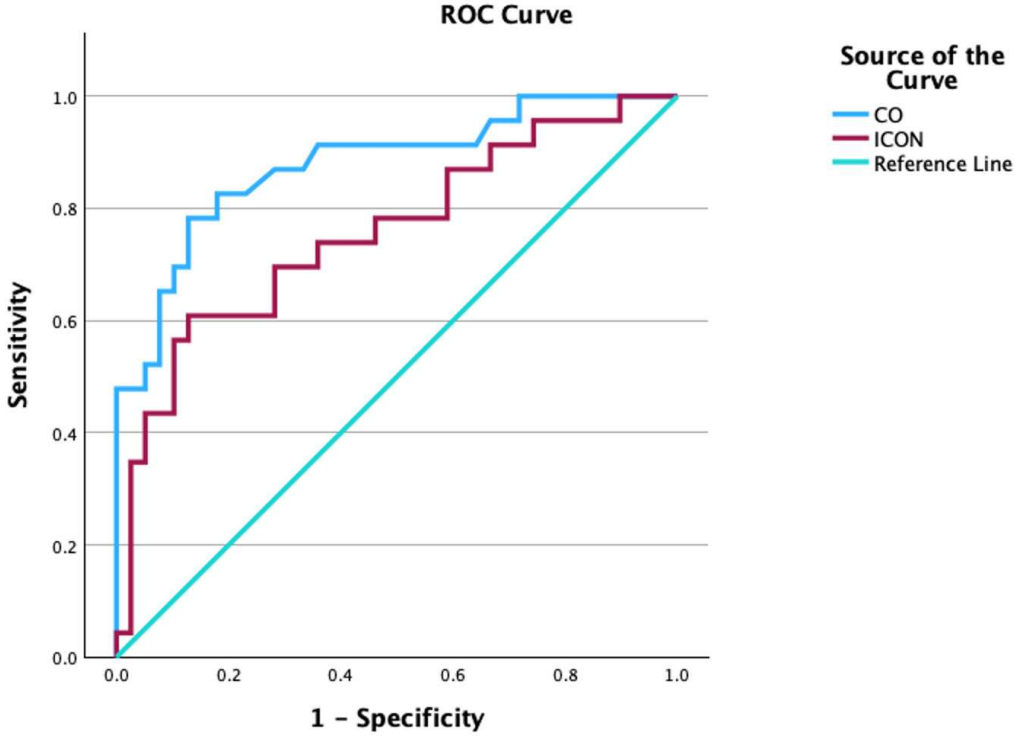

Figure 2. ROC analysis results for CO and ICON

administration enhances cardiac preload and output in responsive patients.8 Traditional static parameters such as blood pressure showed only marginal improvements (ΔSBP: +3 mmHg, ΔDBP: +2 mmHg), reinforcing their limitations in predicting fluid responsiveness.[3,4] The *ICON®*'s ability to provide continuous, dynamic data addresses these limitations, offering a practical alternative to invasive methods like pulmonary artery catheterization.[5,12]

The strong performance of increased CO suggests it could serve as a reliable screening tool for fluid responsiveness, while change in ICON, with its higher specificity, could assist in recognizing individuals who are potentially at higher clinical risk of fluid overload, particularly in cases of myocardial dysfunction.[1] This dual-parameter approach mirrors strategies used in adult critical care, where combining flow-based and contractility markers improves fluid management

precision.[13,14] However, pediatric-specific validation remains essential due to developmental differences in cardiovascular physiology.[14,15,16]

The clinical implications of these findings should be noted. First, CO cutoff of 5.35% provides a clear threshold for clinicians to identify fluid-responsive patients, potentially reducing unnecessary fluid administration.[11,17,18] Second, the moderate *ICON®* specificity from the index of contractility suggests it could be particularly useful in patients with suspected cardiac dysfunction, where fluid overload carries greater risks.[19,20] Third, the non-invasive nature of *ICON®* makes it suitable for repeated measurements, allowing for dynamic assessment of fluid status.[7,21,22]

Interestingly, a previous study in adult ICU patients using electrical cardiometry reported that a ΔCO threshold of 12.5% was effective in predicting fluid responsiveness. This cut-off demonstrated strong diagnostic performance, reflected by an AUC of 0.90, with 90% sensitivity and 70% specificity.[23] Compared to our pediatric cohort, the cut-off we identified (5.35%) was substantially lower, yet maintained comparable diagnostic accuracy (AUC 0.878). This discrepancy may reflect developmental differences in cardiovascular physiology, as children have smaller intravascular volumes and more compliant myocardium, potentially requiring less absolute volume shift to generate meaningful cardiac output changes. Additionally, our study demonstrated higher specificity, which may enhance clinical decision-making when aiming to avoid fluid overload in critically ill children.[23-25]

Despite these strengths, the study has limitations. The single-center design and lack of multivariate analysis may affect generalizability. Additionally, the absence of a DeLong test to statistically compare AUCs means the superiority of CO over the index of contractility should be interpreted cautiously. Future multicenter studies with larger cohorts should explore additional *ICON®*-derived parameters (e.g., thoracic fluid content) and validate these findings in diverse pediatric populations.

Conflict of interest

None declared.

Acknowledgments

The authors extend their appreciation to the pediatric emergency physicians, residents, and nursing personnel at the Emergency and Pediatric Intensive Care Units of Dr. Cipto Mangunkusumo General Hospital, Jakarta, Indonesia. Their assistance during the data collection phase was instrumental to the successful completion of this study.

Funding acknowledgment

This research was conducted without external funding support from governmental, commercial, or non-profit organizations.

References

1. Harley A, George S, Phillips N, King M, Long D, Keijzers G, *et al*. Resuscitation with early adrenaline infusion for children with septic shock: a randomized pilot trial. Pediatr Crit Care Med. 2024;25:106-17. DOI: https://doi.org/10.1097/pcc.0000000000003351
2. Song LL, Geng ZY, Ma W, Liu YF, Wang DX. Dynamic variables predict fluid responsiveness in pre-school and school children undergoing neurosurgery: a prospective observational study. Transl Pediatr. 2021;10:2972-84. DOI: https://doi.org/10.21037/tp-21-281
3. Gan H, Cannesson M, Chandler JR, Ansermino JM. Predicting fluid responsiveness in children. Anesth Analg. 2013;117:1380-92. DOI: https://doi.org/10.1213/ane.0b013e3182a9557e
4. Lee JH, Kim EH, Jang YE, Kim HS, Kim JT. Fluid responsiveness in the pediatric population. Korean J Anesthesiol. 2019;72:429-40. DOI: https://doi.org/10.4097/kja.19305 Erratum in: Korean J Anesthesiol. 2019;72:624. DOI: https://doi.org/10.4097/kja.19305.c1 Erratum in: Korean J Anesthesiol. 2021;74:188. DOI: https://doi.org/10.4097/kja.19305.e1
5. Pereira de Souza Neto E, Grousson S, Duflo F, Ducreux C, Joly H, Convert J, *et al*. Predicting fluid responsiveness in mechanically ventilated children under general anaesthesia using dynamic parameters and transthoracic echocardiography. Br J Anaesth. 2011;106:856-64. DOI: https://doi.org/10.1093/bja/aer090
6. Sanders M, Servaas S, Slagt C. Accuracy and precision of non-invasive cardiac output monitoring by electrical cardiometry: a systematic review and meta-analysis. J Clin Monit Comput. 2020;34:433-60. DOI: https://doi.org/10.1007/s10877-019-00330-y
7. Yassen KA, Al Ghadeer Z, AlHejji F, Alothman F, Alethan H, Al Ali D, *et al*. The role of electrical cardiometry in paediatrics and neonatal anaesthesia and intensive care: a narrative review. Anest Crit Care. 2022;04:73-83. DOI: https://doi.org/10.26502/acc.040

8. Kadafi KT, Latief A, Pudjiadi AH. Determining pediatric fluid responsiveness by stroke volume variation analysis using ICON® electrical cardiometry and ultrasonic cardiac output monitor: a cross-sectional study. Int J Crit Illn Inj Sci. 2020;10:123-8. DOI: https://doi.org/10.4103/ijciis.ijciis_87_18
9. Greiwe G, Saad R, Hapfelmeier A, Neumann N, Tariparast P, Saugel B, *et al*. Electrical cardiometry for non-invasive cardiac output monitoring: a method comparison study in patients after coronary artery bypass graft surgery. J Clin Monit Comput. 2025;39:371-6. DOI: https://doi.org/10.1007/s10877-024-01246-y
10. Bernstein DP. Impedance cardiography: pulsatile blood flow and the biophysical and electrodynamic basis for the stroke volume equations. J Electr Bioimp. 2010;1:2-17. DOI: https://doi.org/10.5617/jeb.51
11. Zhang Y, Ding Y, Zhang J, Huang T, Gao J. Tidal volume challenge-induced hemodynamic changes can predict fluid responsiveness during one-lung ventilation: an observational study. Front Med (Lausanne). 2023;10:1169912. DOI: https://doi.org/10.3389/fmed.2023.1169912
12. Rajput RS, Das S, Chauhan S, Bisoi AK, Vasdev S. Comparison of cardiac output measurement by noninvasive method with electrical cardiometry and invasive method with thermodilution technique in patients undergoing coronary artery bypass grafting. World J Cardiovasc Surg. 2014;4:123-30. DOI: http://dx.doi.org/10.4236/wjcs.2014.47019
13. Sakka SG. Hemodynamic monitoring in the critically ill patient-current status and perspective. Front Med (Lausanne). 2015;2:44. DOI: https://doi.org/10.3389/fmed.2015.00044
14. Monge García MI, Gil Cano A, Gracia Romero M. Dynamic arterial elastance to predict arterial pressure response to volume loading in preload-dependent patients. Crit Care. 2011;15:R15. DOI: https://doi.org/10.1186/cc9420
15. Sharma S, Ramachandran R, Rewari V, Trikha A. Evaluation of electrical cardiometry to assess fluid responsiveness in patients with acute circulatory failure: a comparative study with transthoracic echocardiography. Indian J Crit Care Med. 2024;28:650-6. DOI: https://doi.org/10.5005/jp-journals-10071-24753
16. Rao SS, Lalitha AV, Reddy M, Ghosh S. Electrocardiometry for hemodynamic categorization and assessment of fluid responsiveness in pediatric septic shock: a pilot observational study. Indian J Crit Care Med. 2021;25:185-92. DOI: https://doi.org/10.5005/jp-journals-10071-23730
17. Awadhare P, Patel R, McCallin T, Mainali K, Jackson K, Starke H, *et al*. Non-invasive cardiac output monitoring and assessment of fluid responsiveness in children with shock in the emergency department. Front Pediatr. 2022;10:857106. DOI: https://doi.org/10.3389/fped.2022.857106
18. Weber T, Wagner T, Neumann K, Deusch E. Low predictability of three different noninvasive methods to determine fluid responsiveness in critically ill children. Pediatr Crit Care Med. 2015;16:89-94. DOI: https://doi.org/10.1097/pcc.0000000000000364
19. Hhassan E, Khaled H, Gamal H, Rania M, Samir EH. Electrical cardiometry versus carotid doppler in assessment of fluid responsiveness in critically ill septic patients. Egypt J Crit Care Med. 2021;8:96-113. DOI: https://doi.org/10.1097/EJ9.0000000000000035
20. Yassen KA, Aljumaiy W, Alherz I, AlMudayris LA, Al Bunyan SA, AlSubaie RS, *et al.* Non-invasive cardiac output monitoring with electrical cardiometry during laparoscopic cholecystectomy surgery, a cross-sectional study. J Clin Med. 2025;14:2228. DOI: https://doi.org/10.3390/jcm14072228
21. Elbagoury MM, Hikel KEAli, Elgebaly AS, Abdelrahman RS, Abu Sabaa MA. Thoracic fluid content measured by electrical cardiometry as a predictor of weaning outcomes from mechanical ventilator in adult patients after cardiac surgery: a prospective, observational study. Bali J Anesthesiol. 2024;8:7-13. DOI: https://doi.org/10.4103/bjoa.bjoa_227_23
22. Schwarz CE, O'Toole JM, Healy DB, Panaviene J, Livingstone V, Dempsey EM. Electrical cardiometry during transition and short-term outcome in very preterm infants: a prospective observational study. Eur J Pediatr. 2024;183:1629-36. DOI: https://doi.org/10.1007/s00431-023-05387-1
23. Soliman RA. Prediction of fluid status and survival by electrical cardiometry in septic patients with acute circulatory failure. Egypt J Crit Care Med. 2017;5:65-8. DOI: https://doi.org/10.1016/j.ejccm.2017.03.001
24. Sumbel L, Annamalai MR, Wats A, Salameh M, Agarwal A, Bhalala U. Noninvasive cardiac output monitoring using electrical cardiometry and outcomes in critically ill children. J Pediatr Intensive Care. 2020;11:114-9. DOI: https://doi.org/10.1055/s-0040-1718867
25. Davis AL, Carcillo JA, Aneja RK, Deymann AJ, Lin JC, Nguyen TC, *et al*. American College of Critical Care Medicine clinical practice parameters for hemodynamic support of pediatric and neonatal septic shock. Crit Care Med. 2017;45:1061-93. DOI: https://doi.org/10.1097/ccm.0000000000002425 Erratum in: Crit Care Med. 2017;45:e993. DOI: https://doi.org/10.1097/CCM.0000000000002573
26. Pedgaonkar RA, Singh, NG, Dhananjaya M, *et al*. Comparison of noninvasive cardiac output monitoring by electrical cardiometry with transthoracic echocardiography in postoperative paediatric cardiac surgical patients - a prospective observational study. Annals of Cardiac Anaesthesia 26;4:380-385. DOI: https://doi.org/10.4103/aca.aca_9_23