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Noninvasive Continuous Cardiac Output Monitoring In Shocked Children: Validity & Age Difference Of Estimated Continuous Cardiac Output

Seham Awad ElSherbini[1], Sally Kamal Ibrahim Ishak[1], Doaa Meshref Osman Mohamed[1], Ahmed Said Behairy[1], Bassem Saad Refaie Abdeldaim[1*]
[1]Department of Pediatrics, Faculty of Medicine, Cairo University, Egypt.

Abstract
Background: *Shock in pediatric patients leads to significant morbidity and mortality if not promptly recognized and managed. Continuous cardiac output (CO) monitoring is crucial in guiding treatment, but traditional methods are invasive. Estimated continuous cardiac output (esCCO) offers a noninvasive alternative using pulse wave transit time.*
Aim: *To assess the accuracy of esCCO compared to transthoracic echocardiography (TTE) for CO monitoring in critically ill children with shock, and to explore the effect of age on its validity.*
Methods: This prospective observational study included 110 pediatric patients (aged 1 month to 12 years) admitted to the ICU with shock. CO was measured using esCCO and TTE on admission, at 24 hours, and at 48 hours. Clinical data, vasoactive use, and outcomes were recorded. Correlation and agreement between esCCO and TTE measurements were analyzed using Spearman's test and Bland–Altman analysis.
Results: *A strong correlation between esCCO and TTE was observed among children older than 7 years at all-time points ($r > 0.9$, $p < 0.001$). Agreement was poor among younger children. esCI did not significantly change over time, while esSV declined among children <7 years ($p = 0.03$). Mortality was weakly associated with lower esCI and higher esSV. ROC analysis showed esCI had poor predictive value for mortality (AUC = 0.626).*
Conclusion: *esCCO correlates well with TTE in older children and can serve as a reliable noninvasive tool for CO monitoring in this subgroup. Its utility in younger children remains limited.*

Keywords: *esCCO, transthoracic echocardiography, TTE, cardiac output monitoring.*

INTRODUCTION

Shock is a state of tissue hypoperfusion either due to inadequate oxygen delivery that fails to meet metabolic demands, increased oxygen consumption, inadequate oxygen utilization, or a combination of these factors. When oxygen demand exceeds oxygen supply, tissue oxygenation, nutrient delivery, and eventually cell death are severely compromised. Shock can cause damage to all tissues and progress quickly to multiorgan failure. In order to prevent irreversible cell death, early recognition and treatment of shock is crucial (1).

Monitoring cardiac output (CO) allows early detection of hemodynamic instability and may be used to guide intensive care, aiming to reduce morbidity and mortality in high-risk patients. In the past decade, continuous cardiac output (CCO) was commonly obtained by pulmonary artery catheter (PAC) with integrated heating filaments. The risk–benefit ratio of right heart catheterization simply for CO determination has been questioned due to associated complications and the availability of less invasive alternatives (2).

Thermodilution using the pulmonary artery catheter has been most commonly used to measure cardiac output in the adult population. The limitations of this technique are well-documented and various strategies have been developed to enhance accuracy and precision (3). However, catheter insertion is difficult in smaller patients (5–10 kg) and those with aberrant cardiopulmonary anatomy (4).

Because it does not require right heart catheterization, transpulmonary thermodilution (TPTD) usually is considered a less invasive method for hemodynamic monitoring. For the past 15 years, measurement of cardiac output in children by TPTD has been possible. This method is now incorporated in the PiCCO device (Pulsion, Munich, Germany), which combines two different approaches for the measurement of

cardiac output: TPTD and arterial pressure continuous cardiac output based on the analysis of the arterial pressure waveform (5).

Non-invasive CO measurement with transthoracic echocardiography (TTE) has been validated in other studies. An excellent correlation between TTE and pulmonary artery catheter (PAC) was shown in patients with a broad range of diagnoses, including sepsis. The TTE repeatability was good. It was also shown that TTE was feasible for 95% of patients admitted to the intensive care unit (ICU). TTE has the advantage of being non-invasive, painless, and immediately feasible in patients with spontaneous breathing or mechanical ventilation (6).

Arterial waveform-based CO monitoring is frequently used in current medical practice, but it still requires arterial puncture. Pulse wave transit time has good correlation with stroke volume. Pulse wave transit time consists of a pre-ejection period, pulse wave transit time through the artery, and pulse wave transit time through the peripheral arteries, which compensates for the effect of changes in systemic vascular resistance (SVR) (7).

Based on the relationship between pulse wave transit time and stroke volume, the noninvasive device developed by Sugo et al. provides estimated continuous cardiac output (esCCO) measurements using electrocardiogram (ECG), pulse oximeter wave, and arterial blood pressure. It has the great advantage of simplifying CO measurement by combining the results of these familiar noninvasive monitoring techniques. It is easy to use, inexpensive, and requires no consumable items such as catheters. Thus, it may be a useful technique for optimizing medical treatment. Sugo et al. confirmed the accuracy of esCCO measurement in animal experiments using electromagnetic flow meters (8). In a previous study, esCCO was compared with continuous thermodilution CO (TDCO) measurements in 36 postoperative cardiac surgery patients. The results of clinical use of esCCO suggest that its measurement accuracy is comparable to the thermodilution method, although the number of patients was not large and esCCO was not used for patients with differing backgrounds (9).

The present study aimed to compare between esCCO and TTE measurements of CO to reflect the accuracy of esCCO measurements as a bedside non-invasive measure among critically ill children.

PATIENTS AND METHODS

Population of study & disease condition: The best of our knowledge this is the first study to compare escco to echocardiography among pediatric patients with shock at admission, after 24 hours, and after 48 hours. Pediatric patients aged between 1 month and 12 years' old who were admitted to the intensive care unit (ICU) and required CO measurement to manage their circulation from January 2023 till end of May 2024.

Study setting: Pediatric intensive care unit at Cairo University Specialized Pediatric Hospital; Japanese specialized hospital.

Inclusion criteria: Pediatric patients aged between 1 month and 12 years old and pediatric Patients fulfilled the criteria of shock according to the international Surviving Sepsis Campaign (SSC) (10).

Exclusion criteria: Patients with marked arrhythmias**,** patients with known congenital heart disease, neonates and patients with duration of stay in PICU less than 4 hours.

Methods

Patient history including age, sex, height, and weight was documented, along with clinical examination findings. Organ dysfunction was assessed using the modified SOFA score on admission, at 24 hours, and at 48 hours. The use of vasoactive agents was recorded, including the type, dose, and number of agents administered. Hemodynamic parameters were monitored throughout the study period, and clinical outcomes such as in-hospital mortality and the need for mechanical ventilation were also evaluated.

esCCO measurements (on admission, at 24 hours, and at 48 hours)

Our study was the first one to use this approach in a comparative design among different age groups.

Estimated Continuous Cardiac Output (esCCO):

As a noninvasive method allowing continuous estimation of CO, the esCCOTM technique represents an alternative to more invasive monitoring methods (11). This technology was derived from pulse contour analysis. Cardiac output may be derived from pulse pressure information via: CO = SV × HR = （K × PP) × HR, where CO: cardiac output; SV: stroke volume; K: constant; PP: pulse pressure; HR: Heart Rate. It was noted that pulse wave transit time (PWTT) was a better correlation with stroke volume than pulse pressure and stroke volume. PWTT was then incorporated into the CO estimation equation. PWTT is the time between the peak of the R-wave on the ECG and the start of the pulsatile flow on the plethysmograph. This technology is used by proprietary software on the Nihon Kohden® monitors and requires no further specialized equipment or probes (12). The accuracy of a dynamic trend of esCCO may not be affected by the calibration methods, and the esCCO measurement by the non-invasive calibration method may be an effective device similar to that by the invasive calibration method (13). ECG, pulse oxymetry wave, arterial blood pressure, and pulse wave transit time (PWTT) was obtained using a BSM-9101 bedside monitor (Nihon Kohden, Tokyo, Japan) and transmitted to a personal computer with a c-compiled program for esCCO calculation. CO was measured using an Edwards Vigilance II Monitor (or an Edwards CEDV Monitor, depending on availability) (Edwards Lifesciences, Irvine, CA). ECG monitoring was performed using lead II, and a pulse oximeter probe was placed on a fingertip.

TTE MEASUREMENTS (ON ADMISSION, 24 HOURS, 48 HOURS).

The TTE measurements were taken by an investigator blinded to the measurements determined by esCCO. All TTE measurements were performed using a 'Sonosite® MicroMaxx' with a probe of 2–4 MHz. The Doppler estimated CO (CO_{TTE}) was derived from the Doppler estimated SV using the velocity–time integral (VTI) of flow through the left ventricular outflow tract (LVOT), the diameter of the LVOT, and HR recorded during the imaging study, using the following formula:

COP = (VTILVOT× (diameter of LVOT)2×Π4) × (VTILVOT× (diameter of LVOT)2×Π4) × HR

Aortic VTI was recorded by pulsed-wave Doppler from an apical long-axis view by placing a 5 mm Doppler sample volume in the LVOT at the level of the aortic valve. The VTI value was average over three consecutive measurements. The diameter for LVOT was measured at the aortic annulus from the inner edge to inner edge in a parasternal long-axis view.

Systemic vascular resistance (SVR) was estimated using the equation: SVR (DYN cm^{-5}/m5) = (MAP—CVP) × 80 COT_{TES} VR (dyn s cm-5) = (MAP-CVP) × 80 COTT

RESULTS

Table (1): Basic demographic and clinical characteristics among patients.

	Total (n=110)	Less than 7 yrs (n=82)	More than 7 yrs (n=28)
Sex Male Female	 53 (48.2) 57 (51.8)	 42 (51.2) 40 (48.8)	 11 (39.3) 17 (60.7)
Age (Median, IQR) in years	2, 7.07	1, 1.59	10, 3
Weight (Median, IQR) in kg	10, 14	9, 5	30, 12
Height (Median, IQR) in cm	81.5, 45.75	73, 24	135, 29.25
Body surface area (Median, IQR) in m^2	0.47, 0.5	0.43, 0.2	1, 0.3

a: Chi-square test. b: Mann-Whitney test.

The study included 53 (48.2%) males and 57 (51.8%) female. Patients' median age, weight, height, and body surface area was as follows: 2 years, 10 kgs, 81.5 cm, and 0.47 m^2 respectively

Table (2): Estimated continuous cardiac output monitoring (esCCO) at different time points.

		esCI	esSV
Total (n=110)	On admission	9, 7	28, 6
	At 24 hrs	9, 6.6	28, 6
	At 48 hrs	9, 7	28, 6
	P1	0.403	0.055
Less than 7 yrs (n=82)	On admission	10, 3	28, 5
	At 24 hrs	10, 3	27, 6
	At 48 hrs	10, 3	27, 4
	P2	0.601	**0.03**
More than 7 yrs (n=28)	On admission	3.4, 0.0	37, 13
	At 24 hrs	3.3, 0.4	36.5, 13
	At 48 hrs	3.5, 0.0	40, 17
	P3	0.575	0.434

P1: Friedman test among all patients. p2, p3: Friedman test among same group.

Estimated continuous cardiac output monitoring (esCCO) was measured on admission, at 24 hrs, and at 48 hrs, where esCI didn't show significant changes over time points, while esSV showed significant decrease over time points only among children younger than 7 yrs (p1=0.03)

Table (3): Estimated continuous cardiac output monitoring (esCCO), inotropic score, and vasoactive score at 48 hrs, according to age group.

Median, IQR	Total (n=110)	Less than 7 yrs (n=82)	More than 7 yrs (n=28)	P value *
esCI l/min/m2	9, 7	10, 3	3.5, 0.0	**<0.001**
esSV ml	28, 6	27, 4	40, 17	**<0.001**
Inotropic score	10, 15	12.5, 15	7.5, 15	0.086
Vasoactive score	20, 28	25, 30	12.75, 13	**0.032**

*: Mann-Whitney test.

At 48 hrs, esCI and vasoactive score were significantly higher among younger children than older ones, while esSV was significantly lower among younger children, however no significant difference encountered regarding inotropic score

Table (4): Correlation between "CVP, esCI, esSV, CO, CI, SV, VTI and SVRI" and inotropic score, and vasoactive score at 48 hrs.

	Inotropic score		Vasoactive score	
	r	**p ***	**r**	**p ***
CVP(cm H2O)	-0.706	**<0.001**	-0.749	**<0.001**
esCI l/min/m2	-0.047	0.626	-0.059	0.538
esSV ml	-0.415	**<0.001**	-0.476	**<0.001**
CO l/min	-0.360	**<0.001**	-0.420	**<0.001**
CI l/min/m2	-0.628	**<0.001**	-0.681	**<0.001**
SV ml	-0.389	**<0.001**	-0.441	**<0.001**
VTI cm	-0.607	**<0.001**	-0.673	**<0.001**
SVRI dyn s/ cm5/m2	0.178	0.063	0.232	**0.015**

*: Spearman correlation.

There's a negative moderate correlation between CVP (r=-0.706), esSV (r=-0.415), CO (r=-0.360), CI (r=-0.628), SV (r=-0.389), VTI (r=-0.607) and inotropic and vasoactive scores at 48 hrs. Also, a positive weak correlation between SVRI (r=0.232) and vasoactive score.

Table (5): Correlation between esCCO and TTE readings on admission, at 24 hrs and at 48 hrs according to age group.

		Total (n=110)		Less than 7 yrs (n=82)		More than 7 yrs (n=28)	
		r	p *	r	p *	r	p *
On admission	CI	-0.011	0.909	0.017	0.877	0.901	**<0.001**
	SV	0.458	**<0.001**	0.082	0.463	0.980	**<0.001**
At 24 hrs	CI	0.052	0.587	0.164	0.141	0.826	**<0.001**
	SV	0.528	**<0.001**	0.186	0.094	0.974	**<0.001**
At 48 hrs	CI	0.031	0.747	0.207	0.063	0.947	**<0.001**
	SV	0.550	**<0.001**	0.221	**0.046**	0.980	**<0.001**

*: Spearman correlation.

There's a positive mild correlation between esSV and SV_TTE on admission (r=0.458), at 24 hrs (r=0.528) and at 48 hrs (r=0.550) among all children. Also, there's a positive weak correlation between esSV and SV_TTE at 48 hrs (r=0.221) among younger children. However, there's a positive strong correlation between both CI and SV measured by esCCO and TTE on admission (r=0.901, 980), at 24 hrs (r=0.826, 0.974) and at 48 hrs (r=0.947, 980) among older children.

Table (6): Bland-Altman method to compare the differences between esCCO and TPTD according to age groups, on admission, at 24 hrs, and at 48 hrs.

			Mean	Percentage error
On admission	Total (n=110)	mean CI	5.5794	
		diff CI	-4.4889	118.285
		mean SV	23.815	
		diff SV	-11.4791	73.499
	Less than 7yrs (n=82)	mean CI	6.25	
		diff CI	-5.99	78.4
		mean SV	19.34	
		diff SV	-15.3	70.5
	More than 7yrs (n=28)	mean CI	3.59	
		diff CI	-0.86	8.7
		mean SV	36.92	
		diff SV	-0.3	8.6
At 24 hrs	Total (n=110)	mean CI	5.5936	
		diff CI	-4.58	118.8
		mean SV	23.7895	
		diff SV	-11.0391	72.63
	Less than 7yrs (n=82)	mean CI	6.29	
		diff CI	-6.12	76.3
		mean SV	19.2	
		diff SV	-14.84	69.3
		mean CI	3.55	

	More than 7yrs (n=28)	diff CI	-0.06	9.94
		mean SV	37.19	
		diff SV	0.093	8.9
At 48 hrs	Total (n=110)	mean CI	5.59	
		diff CI	-4.7	122.368
		mean SV	24.1795	
		diff SV	-11.5955	74.18
	Less than 7yrs (n=82)	mean CI	6.29	
		diff CI	-6.29	79.46
		mean SV	19.38	
		diff SV	-15.5	71.8
	More than 7yrs (n=28)	mean CI	3.54	
		diff CI	-0.089	6.58
		mean SV	38.2	
		diff SV	-0.089	8.4

Bland-Altman method was used to assess the differences between esCCO and TTE, where the differences between esCCO and TTE are plotted against their means, with the 95% confidence intervals. Percentage error was calculated as: (difference/mean) *100%, then interpreted to compare both methods; if percentage error ≤30% then good agreement is considered between methods of measurement, and if >30% then poor agreement is considered. As illustrated in table (25) and fig 26-31, good agreement between methods was encountered among older children regarding both CI and SV at all-time points; that concur the usefulness of esCCO instead of TTE among older children. When measured **on admission**, we've noticed a bias of -0.86 l/min, limits of agreement of -0.5464 to -1.1736 l/min, and percentage error of 8.7% regarding **CI** and a bias of -0.3 l/min, limits of agreement of 2.8752 to -3.4752 l/min, and percentage error of 8.6% regarding **SV**.
When measured **at 24 hrs**, we've noticed a bias of -0.06 l/min, limits of agreement of 0.2928 to -0.4128 l/min, and percentage error of 9.94% regarding **CI** and a bias of 0.093 l/min, limits of agreement of 3.425 to -3.239 l/min, and percentage error of 8.9% regarding **SV**.
When measured **at 48 hrs**, we've noticed a bias of -0.809 l/min, limits of agreement of 0.14424 to -0.32224 l/min, and percentage error of 6.58% regarding **CI** and a bias of -0.089 l/min, limits of agreement of 3.1254 to -3.3034 l/min, and percentage error of 8.4% regarding **SV**.
However, a poor agreement between methods was encountered among younger children regarding both CI and SV at all-time points.

Table (7): Correlation between mortality and CVP, HR, Blood Pressure, TTE and esCCO parameters, inotropic and vasoactive scores on admission.

	r	P
CVP(cm H2O)	-0.047	0.625
HR (beat/min)	-0.179	0.061
SBP (mm Hg)	0.158	0.099
DBP(mm Hg)	0.149	0.119
MAP(mm Hg)	0.181	0.059
CO l/min	0.294	**0.002**
CI l/min/m2	-0.286	**0.002**
SV ml	0.288	**0.002**
VTI cm	0.099	0.306
SVRI dyn s/ cm5/m2	-0.283	**0.003**

EsCI l/min/m2	-0.219	**0.022**
EsSV ml	0.352	**<0.001**
Inotropic score	-0.260	**0.006**
Vasoactive score	-0.369	**<0.001**

There's a weak positive correlation between mortality and CO (r=0.294), SV (r=0.288) and esSV (r=0.352), also, there's weak negative correlation between mortality and CI (r=-0.286), SVRI (r=-0.283), and esCI (r=-0.219).

Table (8): ROC curve analysis of mortality and esCCO parameters on admission.

	Cut-off	Sensitivity	Specificity	AUC (95% CI)	p
esCI l/min/m2	12.5	1.8%	96.4%	0.626 (0.521-0.731)	**0.023**
esSV ml	16.5	98.2%	1.8%	0.297 (0.200-0.395)	**<0.001**

ROC curve analysis was done to analyze prediction of mortality and esCCO parameters on admission, where esCI and esSV predicted mortality at the illustrated cut-off points, sensitivity and specificity. However, esSV is considered non-predictor because AUC is less than 0.5. Also, esCI is considered a poor predictor because AUC is less than 0.7.

DISCUSSION

The study included 53 (48.2%) males and 57 (51.8%) female. Patients' median age, weight, height, and body surface area was as follows: 2 years, 10 kgs, 81.5 cm, and 0.47 m^2 respectively

Estimated continuous cardiac output monitoring (esCCO) was measured on admission, at 24 hrs, and at 48 hrs, where esCI didn't show significant changes over time points, while esSV showed significant decrease over time points only among children younger than 7 yrs (p1=0.03);

At 48 hrs, esCI and vasoactive score were significantly higher among younger children than older ones, while esSV was significantly lower among younger children, however no significant difference encountered regarding inotropic score.

There's a negative moderate correlation between CVP (r=-0.706), esSV (r=-0.415), CO (r=-0.360), CI (r=-0.628), SV (r=-0.389), VTI (r=-0.607) and inotropic and vasoactive scores at 48 hrs. Also, a positive weak correlation between SVRI (r=0.232) and vasoactive score; as shown in table (22).

There's a positive mild correlation between esSV and SV_TTE on admission (r=0.458), at 24 hrs (r=0.528) and at 48 hrs (r=0.550) among all children. Also, there's a positive weak correlation between esSV and SV_TTE at 48 hrs (r=0.221) among younger children. However, there's a positive strong correlation between both CI and SV measured by esCCO and TTE on admission (r=0.901, 980), at 24 hrs (r=0.826, 0.974) and at 48 hrs (r=0.947, 980) among older children

There's a weak positive correlation between mortality and CO (r=0.294), SV (r=0.288) and esSV (r=0.352), also, there's weak negative correlation between mortality and CI (r=-0.286), SVRI (r=-0.283), and esCI (r=-0.219); as shown in table (26).

which came along with **Feissel et al. (14)** who found a linear correlation between CO measured by esCCO and TTE before and after fluid administration (r2 = 0.71, p < 0.0001 and r2 = 0.81 p < 0.0001 respectively).

Along with our results, **Bataille et al. (15)** revealed a moderate positive correlation between esCCO and CO_TTE (r=0.61, P<0.001).

Likewise, **Sugo et al. (16)** showed a strong positive correlation between esCCO & echo Doppler aortic velocity-time integral; esSV& VTIao-SV (r=0.82, p<0.01) and esCCO& VTIao-CO (r=0.87, p<0.01).

In addition, **Erkus et al. (17)** found a significant positive correlation was found between esCCO and echoCO (r = 0.785, p< 0.001).

Also, **Sugo et al. (16)** had compared esCCO with CO measured by echo Doppler aortic velocity-time integral (VTIao_CO) during exercise and found a strong positive correlation between them (r=0.87).

Moreover, **Takakura et al. (18)** had compared esCCO to the thermo-dilution cardiac output (TDCO) under different respiratory conditions where a strong positive correlation was found both before and after extubation (r=0.859 and 0.818 respectively).
In addition, **Terada et al. (13)** had compared esCCO and TTE for noninvasively measuring CO in pediatric patients undergoing kidney transplant surgery with a positive correlation between them (r=0.75).
Bland-Altman method was used to assess the differences between esCCO and TTE and how much they're in agreement, good agreement between methods was encountered among only **older children** regarding both CI and SV at all-time points; that concur the usefulness of esCCO instead of TTE among older children.
When measured **on admission**, we've noticed a bias of -0.86 l/min, limits of agreement of -0.5464 to -1.1736 l/min, and percentage error of 8.7% regarding **CI** and a bias of -0.3 l/min, limits of agreement of 2.8752 to -3.4752 l/min, and percentage error of 8.6% regarding **SV**.
When measured **at 24 hrs**, we've noticed a bias of -0.06 l/min, limits of agreement of 0.2928 to -0.4128 l/min, and percentage error of 9.94% regarding **CI** and a bias of 0.093 l/min, limits of agreement of 3.425 to -3.239 l/min, and percentage error of 8.9% regarding **SV**.
When measured **at 48 hrs**, we've noticed a bias of -0.809 l/min, limits of agreement of 0.14424 to -0.32224 l/min, and percentage error of 6.58% regarding **CI** and a bias of -0.089 l/min, limits of agreement of 3.1254 to -3.3034 l/min, and percentage error of 8.4% regarding **SV**.
However, a poor agreement between methods was noticed among all children and among younger children regarding both CI and SV at all-time points.
Besides, **Feissel et al. (14)** had compared between esCCO and CO_TTE before and after fluid administration, where the bias and limits of agreement (95% confidence interval) between esCCO and CO_TTE were -0.60 L/min (-2.05 to 0.85 L/min) and -0.54 L/min (-1.92 to 0.84 l/min.) respectively, with clinically acceptable limits of agreement, and they concluded that the esCCO monitor can be recommended for critically ill patients.
In addition, **Erkus et al. (17)** found a bias between esCCO and echoCO as -0.36 L/min, limits of agreement were ranged from -1.77 to 1.05 L/min, and percentage errors of measurements of CO was 13% among patients with systolic heart failure.
Sugo et al. (16) had compared esCCO with CO measured by echo Doppler aortic velocity-time integral (VTIao_CO) where bias and precision were 0.33 ± 0.95 L/min with a percentage error of 30.2%.
Moreover, **Takakura et al. (18)** had compared esCCO to the thermo-dilution cardiac output (TDCO) under different respiratory conditions where the respective bias and standard deviation (SD) values were 0.13 L/min and 0.60 L/min before extubation, and − 0.48 L/min and 0.78 L/min after extubation, and percentage errors were 25.1% before extubation and 29.6% after extubation, where esCCO system was considered clinically acceptable to that of TDCO under mechanical ventilation and spontaneous respiration.
Meanwhile, **Terada et al. (13)** had compared esCCO and TTE where the difference in the cardiac index, between the methods, was 0.21 ± 1.01 L/min/ m2 (95% confidence interval, -1.77 to 2.19) and the percentage error was 43.6%; they found poor agreement between the two methods, although a good trend agreement between them (as sensitivity and specificity for cardiac index determination, using esCCO compared to TTE, were 87.5% and 100%, respectively), hence, the esCCO trending ability monitoring in children.
Nevertheless, **Bataille et al. (15)** had showed a bias of 21.6 l/min and limits of agreement from 24.7 to +1.5 l/min, with a percentage error of 49%, and concluded that the performance of the esCCO monitor was not clinically acceptable.
On the other hand, **Stalter et al. (19)** had compared esCCO versus Physioflow among healthy adults where correlation coefficient between both methods was 0.88 ($P < 0.01$) and mean difference was 0.04 ± 1.49 L/min (95% limits of agreement: +2.94 to −3.00 L/min) and concluded that esCCO measurements are accurate, reliable and allow a good estimation of cardiac output on healthy subjects.
ROC curve analysis was done to analyze prediction of mortality and esCCO parameters on admission, where esCI and esSV predicted mortality at the illustrated cut-off points, sensitivity and specificity. However, esSV

is considered non-predictor because AUC is less than 0.5. Also, esCI is considered a poor predictor because AUC is less than 0.7.

CONCLUSION

esCCO is well correlated with TTE in children with shock. esCCO can be used as a noninvasive method for continuous CO monitoring instead of TTE in older children than 7 years with shock. Initial esCI _on admission_ can be used as a predictor for child mortality; however, a poor predictor. esSV on admission shows good agreement and less percentage error with TTE than esCI; as proved by Bland Altman method.

REFERENCES

1. Dell'Anna AM, Torrini F, Antonelli M. Shock: definition and recognition. Hemodynamic Monitoring. 2019:7-20.
2. Huygh J, Peeters Y, Bernards J, Malbrain ML. Hemodynamic monitoring in the critically ill: an overview of current cardiac output monitoring methods. F1000Research. 2016 Dec 16;5:F1000-aculty.
3. Cecconi M, De Backer D, Antonelli M, Beale R, Bakker J, Hofer C, Jaeschke R, Mebazaa A, Pinsky MR, Teboul JL, Vincent JL. Consensus on circulatory shock and hemodynamic monitoring. Task force of the European Society of Intensive Care Medicine. Intensive care medicine. 2014 Dec;40:1795-815.
4. Ricci Z, Pilati M, Favia I, Garisto C, Rossi E, Romagnoli S. Hemodynamic monitoring by pulse contour analysis in critically ill children with congenital heart disease. Pediatric Critical Care Medicine. 2011 Sep 1;12(5):608-9.
5. Monnet X, Teboul JL. Transpulmonary thermodilution: advantages and limits. Critical Care. 2017 Dec;21:1-2.
6. Price S, Nicol E, Gibson DG, Evans TW. Echocardiography in the critically ill: current and potential roles. Intensive care medicine. 2006 Jan;32:48-59.
7. Meng Q, Wang S, Wang Y, Wan S, Liu K, Zhou X, Zhong G, Zhang X, Chen X. Arterial stiffness is a potential mechanism and promising indicator of orthostatic hypotension in the general population. Vasa. 2014 Nov 1;43(6):423-32.
8. Sugo Y, Ukawa T, Takeda S, Ishihara H, Kazama T, Takeda J. A novel continuous cardiac output monitor based on pulse wave transit time. In2010 Annual International Conference of the IEEE Engineering in Medicine and Biology 2010 Aug 31 (pp. 2853-2856). IEEE.
9. Ball TR, Tricinella AP, Kimbrough BA, Luna S, Gloyna DF, Villamaria FJ, Culp Jr WC. Accuracy of noninvasive estimated continuous cardiac output (esCCO) compared to thermodilution cardiac output: a pilot study in cardiac patients. Journal of cardiothoracic and vascular anesthesia. 2013 Dec 1;27(6):1128-32.
10. Weiss SL, Balamuth F, Chilutti M, Ramos MJ, McBride P, Kelly NA, Payton KJ, Fitzgerald JC, Pennington JW. Identification of pediatric sepsis for epidemiologic surveillance using electronic clinical data. Pediatric Critical Care Medicine. 2020 Feb 1;21(2):113-21.
11. Ehlers U, Erlebach R, Brandi G, Stretti F, Valek R, Klinzing S, Schuepbach R. Continuous estimation of cardiac output in critical care: a noninvasive method based on pulse wave transit time compared with transpulmonary thermodilution. Critical care research and practice. 2020;2020(1):8956372.
12. NAIDOO D. Should I Use A Cardiac Output Monitor?.
13. Terada T, Maemura Y, Yoshida K, Samuna R, Oiwa A, Ochiai R. Comparison of estimated continuous cardiac output and transesophageal echocardiography cardiac output for noninvasively measuring cardiac output in pediatric patients undergoing kidney transplant surgery: 3AP4-2. European Journal of Anaesthesiology| EJA. 2014 Jun 1;31:39.
14. Feissel M, Aho LS, Georgiev S, Tapponnier R, Badie J, Bruyere R, Quenot JP. Pulse wave transit time measurements of cardiac output in septic shock patients: a comparison of the estimated continuous cardiac output system with transthoracic echocardiography. PLoS One. 2015 Jun 30;10(6):e0130489.
15. Bataille B, de Selle J, Moussot PE, Marty P, Silva S, Cocquet P. Machine learning methods to improve bedside fluid responsiveness prediction in severe sepsis or septic shock: an observational study. British journal of anaesthesia. 2021 Apr 1;126(4):826-34.
16. SUGO Y, SAKAI T, TERAO M, UKAWA T, OCHIAI R. The agreement and trend ability of a Non-invasive Continuous Cardiac Output Measurement Method Utilizing ECG and SpO 2 Pulse Wave against Echo Doppler during Exercise. **医療機器学**. 2013;83(3):273-82.

17. Erkus ME, Altiparmak IH, Kucuk A, Yalcin F, Demirbag R, Kaya Z, Veeramachaneni R, Indurkar PS. Comparison of estimated continuous cardiac output with echocardiography in patients with systolic heart failure. International Journal of Research in Medical Sciences. 2016 Feb;4(2):369.
18. Takakura M, Fujii T, Taniguchi T, Suzuki S, Nishiwaki K. Accuracy of a noninvasive estimated continuous cardiac output measurement under different respiratory conditions: a prospective observational study. Journal of Anesthesia. 2023 Jun;37(3):394-400.
19. Stalter A, Lanot N, Bridon G, Julian V, Péreira B, Richard R. Validation during exercise of a new device for cardiac output measurement using pulse wave transit time (comparison EsCCO (®) vs. Physioflow (®)). InAnnales de Cardiologie et D'angeiologie 2015 Jan 21 (Vol. 65, No. 1, pp. 1-6).