EGYPTIAN JOURNAL OF ANAESTHESIA
2023, VOL. 39, NO. 1, 418–425
https://doi.org/10.1080/11101849.2023.2209415

Hemodynamic monitoring and correlation between electrical cardiometry and esophageal Doppler in patients undergoing major abdominal surgery

Shady Rady Abdalla, Ahmed Salah Abdelazeem, Tarek Abdelhalium Kaddah, Abla Salah Elhadedy, Hanan Farouk Khafagy, Ahmed Abdalla Mohamed and Ahmed Mohamed Essam

Anesthesia, Intensive Care and Pain Management Department, Theodor Bilharz Research Institute, Giza, Egypt

ABSTRACT

Background: Transesophageal Doppler (TED) is a minimally invasive monitor that allows continuous hemodynamic variables monitoring. Non-invasive electrical cardiometry (EC) and TED methods added an additional facility to monitor cardiac output (CO) continuously and guide fluid management. The aim of this study was to correlate hemodynamic monitoring between non-invasive EC and Esophageal Doppler (ED) in cases undergoing major abdominal surgery.

Methods: This prospective observational study was carried out on 35 adult cases, American Society of Anesthesiologists (ASA) physical status II or III, undergoing major abdominal surgery. Esophageal Doppler and EC were attached to the same patient. Parameters measured were hemodynamic parameters.

Results: Comparison of CO with ICON and ED showed that the ICON mean value ranged from 5.6 to 6.2 l/min, and the ED mean value always ranged from 5.7 to 7.6 l/min with the non-significant difference between the two methods. The precision for the ICON ranged from 15.19 to 17.99% and the precision for ED ranged from 13.39 to 17.08%. At a 15% change in ICON, the ED values' sensitivity was 72.6% and specificity was 30.9% with AUC 0.505.

Conclusion: The agreement between CO measured by EC and ED is acceptable. Both monitored trend changes and guided fluid administration in the operation theater. The EC is as accurate as ED in measuring hemodynamics during major abdominal surgery.

ARTICLE HISTORY
Received 22 January 2023
Revised 22 April 2023
Accepted 27 April 2023

KEYWORDS
Hemodynamic monitoring; electrical cardiometry; esophageal Doppler; abdominal surgery

1. Introduction

Hemodynamics begin with the heart supplying the driving force for all blood flow in the body, representing the governing principles of this blood flow and its behavior in the blood vessels. It is necessary to utilize both non-invasive and invasive mechanical methods to monitor organ blood flow. Manual blood pressure, arterial blood pressure, central venous pressure (CVP), left atrial pressure, and pulmonary wedge pressure (PWP), venous oxygen saturation (SVO_2), and cardiac output (CO) measurements are some of these non-invasive and invasive techniques [1].

Fluid resuscitation can be efficiently used to reduce the length of hospital stay with the use of intraoperative hemodynamic monitoring. It may be possible to administer guided fluid treatment in a goal-directed manner and reduce the hazards associated with inserting a central line and/or pulmonary artery catheter using non-invasive or minimally invasive ways of measuring CO [2].

One of the minimally invasive monitors that enable continuous monitoring of hemodynamic variables is transesophageal Doppler (TED) [3]. For the purpose of estimating CO by the measurement of aortic blood flow (ABF), Doppler techniques are commercially available [4].

The thorax is exposed to a high-frequency, low-alternating electrical current as part of bioimpedance cardiography (ICG). Cardiovascular events and thoracic blood flow are connected to variations in bioimpedance to this current [5].

Minimally invasive TED approaches and non-invasive electrical cardiometry (EC) techniques can be included as a facility to guide fluid management and continually measure CO [6].

In cases undergoing major abdominal surgery, esophageal Doppler and bioimpedance technology for CO/Cardiac Index (CI) readings are not interchangeable with no differences in bioimpedance measures are caused by the surgical incision [7].

This study aimed to compare non-invasive EC and minimally invasive TED hemodynamic monitoring in cases undergoing major abdominal surgery. The primary outcome was correlation between two devices regarding CO measurement. The secondary outcomes were assessment of other hemodynamic parameters as

CONTACT Shady Rady Abdalla Drshady70@yahoo.com Lecturer of Anesthesia, Critical Care and Pain Management Department, Theodor Bilharz Research Institute, Giza, Egypt

CI, SV, SV index, and SVR by the two devices and routine hemodynamic parameters as heart rate (HR) and MAP.

2. Patients and methods

Thirty-five adult cases with American Society of Anesthesiologists (ASA) physical status II or III who were scheduled for major abdominal surgery for cancer of the stomach, colon, bladder, or pancreas at Theodor Bilharz Research Institute participated in this prospective observational research.

After receiving approval from Cairo University Hospitals' Ethical Committee, the study was carried out. The cases provided signed consent after being fully briefed.

Ages under 18 years of age, hemodynamic instability, arrhythmias, being on inotropes (indication of perfusion heart failure characterized by circulatory shock and advanced heart failure), coagulopathies, a history of esophageal pathology, and the requirement for significant intraoperative blood transfusions were all exclusion criteria.

2.1. Study procedures

The monitors were attached to cases as follows: non-invasive blood pressure, ECG, SpO_2, capnography, invasive blood pressure, CVP, anesthetic gas analyzer and temperature.

All cases were given midazolam 70–80 mcg/kg IM (dose range~5 mg) 30–60 minutes before surgery (reduce 50% for chronically ill or geriatric cases).

Anesthesia was induced by intravenous administration of 1–2 μg/kg fentanyl and 2–2.5 mg/kg propofol until losing verbal contact. Muscle relaxation was achieved by intravenous 0.5 mg/kg atracurium, then trachea was intubated, and urinary catheter was inserted. Anesthesia was maintained using 1 MAC sevoflurane with oxygen in air 60% and mechanical ventilation was adjusted to maintain $PaCO_2$ between 30- and 35-mm Hg.

Then, fluids were maintained at a rate of 6–8 ml/kg/h crystalloids intraoperatively which were modified according to cardiac monitoring. If the SV decreased by 10% compared to the post-induction baseline value measured by ED, a 250 ml bolus of colloid solution (hydroxyethyl starch) was administered via rapid infusion with a 50-ml syringe (using colloids up to 1500 ml), fluid challenges was given if patient was fluid responsive and still in need of further fluids, the fluid challenge was repeated until no further increase in stroke volume was occurred and if the patient was still hemodynamically unstable then norepinephrine was added and/or blood transfusion was done based on hemoglobin level (less than 7 g/d) or blood loss more than 20% of total blood volume.

2.2. Cardiac monitoring

The EC device (ICON®; Osypka Medical, Berlin, Germany) was connectedm and the patient demographic and anthropometric data were entered. Four sensors were applied:

The first one was placed approximately 5 cm above left neck base along the course of internal carotid artery, the second one on the left neck base, third one on the left anterior axillary line at the level of xiphoid, then the fourth one approximately 10 to 15 cm below the third one.

The ED (CardioQ, Deltex Medical, Chichester, UK) probe was introduced orally and located about thirty-five to forty cm from the teeth till aortic blood flow signals were identified. Once achieved, satisfactory, the position was maintained by tapping the probe cable to either the patient's face or the endotracheal tube. ED measures the blood flow velocity in descending thoracic aorta. The velocity–time curve provides the distance of blood travelled following the systole and this was multiplied by the cross-sectional area (calculated using a nomogram) to provide SV and CO.

Population characteristics, hemodynamic measurements like heart rate (HR) and mean arterial pressure (MAP), and urine output were recorded. CO (L/minute), cardiac index (CI), stroke volume index (SVI), systemic vascular resistance (SVR), and oxygen delivery index (DO2I) were recorded as cardiac parameters generated by EC and ED. At the T1 baseline, cardiac measurements were collected: T1: Before skin incision, T2: one hour after induction, T3: A half-hour after organ resection, and T4: At the conclusion of the operation.

Measurements were not taken during hemodynamic instability or arrhythmias. After the procedure, 0.05 mg/kg of neostigmine and 0.02 mg/kg of atropine were administered to reverse the muscular relaxation. Meperidine and acetaminophen were administered intravenously every 12 hours to relieve postoperative pain.

2.3. Sample size calculation

Sample size calculation was performed using MedCalc software v16. Assuming a minimum correlation coefficient of (r) of 0.5 and alpha error of 0.05 and beta error of 20% [8]. The minimum sample size required was calculated to be 29 cases. To compensate for dropouts, we increased it to 35 patients.

2.4. Statistical analysis

Statistical analysis was done using SPSS version 18 for Windows. The mean and standard deviation (SD) of quantitative variables were reported, and they were compared for the same group using a paired Student's t-test. Frequency and percentages (%) were used to present qualitative characteristics. Analyzing the sensitivity, specificity, positive predictive value (PPV), and negative predictive value of diagnostic performance (NPV). Agreement: The paired Student's T test was used to compare ICON and ED measurement results. Between ICON and ED, bias and its standard deviation were computed. ICON and ED measurement graphs of modified Bland Altman were made. Pearson correlation was used to measure the strength of the linear relationship between variables. A two tailed *P* value <0.05 was considered significant.

3. Results

Table 1 shows cases' demographic data, ASA status, types, duration of surgery, fluid balance, hemodynamics, HR, and mean blood pressure at different times of follow-up of the studied group.

The precision for the ICON ranged from 15.19 to 17.99% and the precision for ED ranged from 13.39 to 17.08%. At a 15% change in ICON, the ED values' sensitivity was 72.6% and specificity was 30.9% with AUC 0.505. (Table 2, Figure 1A) Mean bias was −0.0257 with SD = 0.39751 with limits of agreement (−0.68–0.81), and the percentage error (PE) ranges from −126.5% to 14.6%. Figure 1B Comparison of CI with ICON and ED showed that ICON mean value ranged from 3 to 4.9 (l/min/m^2) and ED mean value always ranged from 3 to 3.3 (l/min/m2) with non-significant difference between the two methods. The precision for the ICON ranged from 13.4 to 16.25% and the precision for ED ranged from 12.19 to 14.99%. Comparison of SV with ICON and ED showed that ICON mean value range from 69.6 to 77.6 (ml/beat) and ED mean value range from 77.7 to 83.3 (ml/beat) with non-significant difference between the two methods at T1 and T4. The precision for the ICON ranged from 9.23 to 17.27% and the precision for ED ranged from 6.03 to 17.06%. Comparison of SVI with ICON and ED showed that ICON mean value ranged from 37.1 to 42.4 (ml/m^2/

Table 1. Demographic data, ASA status, types, duration of surgery, fluid balance, hemodynamics, HR, and mean blood pressure at different times of followup of the studied group.

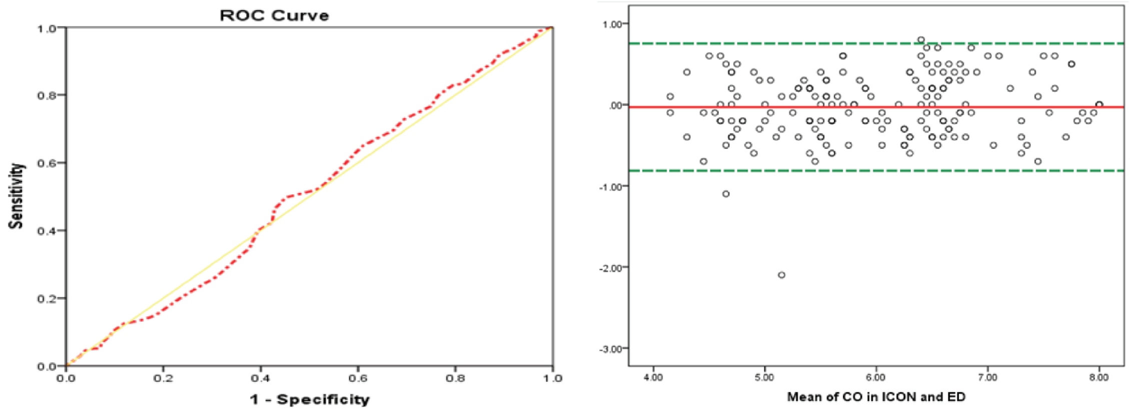
		N = 35
Age (years)		46.0 ± 10.1
Sex	Female	40%
	Male	60%
Weight (Kg)		80.5 ± 11.6
Height (cm)		167.4 ± 8.6
BMI (Kg/m^2)		31.5 ± 3.2
ASA Status		2.4 ± 0.2
Type of surgery	Exploration	34.3%
	Gastrectomy	14.3%
	Radical Cystectomy	20%
	RT Hemicolectomy	14.3%
	Whipple	5.7%
	Radical prostatectomy	2.9%
	Extended Rt Hemicolectomy	2.9%
	Hepaticojejunostomy	2.9%
	Splenectomy	2.9%
Duration of surgery(hrs.)		3.8 ± 1.4
Fluid Input (ml)		4248.6 ± 798.7
Fluid Output (ml)		3068.6 ± 740.7
Mean of HR (beat/min)		79.72 ± 9.6
Mean Blood Pressure (mmHg)		87.3 ± 15.2
HR (beat/min)	T1	78.2 ± 7.9
	T2	84.5 ± 9.6
	T3	79.6 ± 8.7
	T4	76.7 ± 9.1
	T5	79.6 ± 11.1
MBP (mmHg)	T1	76.6 ± 25.9
	T2	90.5 ± 6.9
	T3	88.7 ± 7.3
	T4	90.9 ± 8.5
	T5	89.9 ± 14.2

Note: Data are presented as mean ± SD or frequency (%). BMI: Body mass index, ASA: American Society of Anesthesiologists, HR: Heart rate, MBP: Mean Blood Pressure.

Table 2. Cardiac output (l/min) by the two methods at different time of follow-up.

CO	ICON	ED	Bias	Limits of Agreement	P E	Precision of ICON	Precision of ED	Sn.	Sp.	Area ROC curve	P. value
T1	5.6 ± 0.9	5.7 ± 0.8	−0.13	−0.78–0.52	−5.2	15.26	13.39	72.6	30.9	0.505	0.3
T2	5.9 ± 0.9	6.0 ± 0.9	−0.11	−1.03–0.81	−8.2	15.19	14.57				0.2
T3	6.0 ± 1.0	6.0 ± 0.9	0.05	−0.70–0.80	14.6	15.77	14.80				0.4
T4	6.2 ± 1.0	6.2 ± 1.1	−0.01	−0.73–0.72	−126.5	16.61	16.97				0.9
T5	6.2 ± 1.1	7.6 ± 8.5	0.06	−0.68–0.80	11.8	17.99	17.08				0.4

Note: CO: Cardiac output, Sn: Sensitivity, Sp: Specificity.



(A) (B)

Figure 1. (A) Receiver operator characteristic curve demonstrating the sensitivity and the specificity of ICON and ED, (B) Bland Altman analysis of ICONCO and EDCO of CO results.

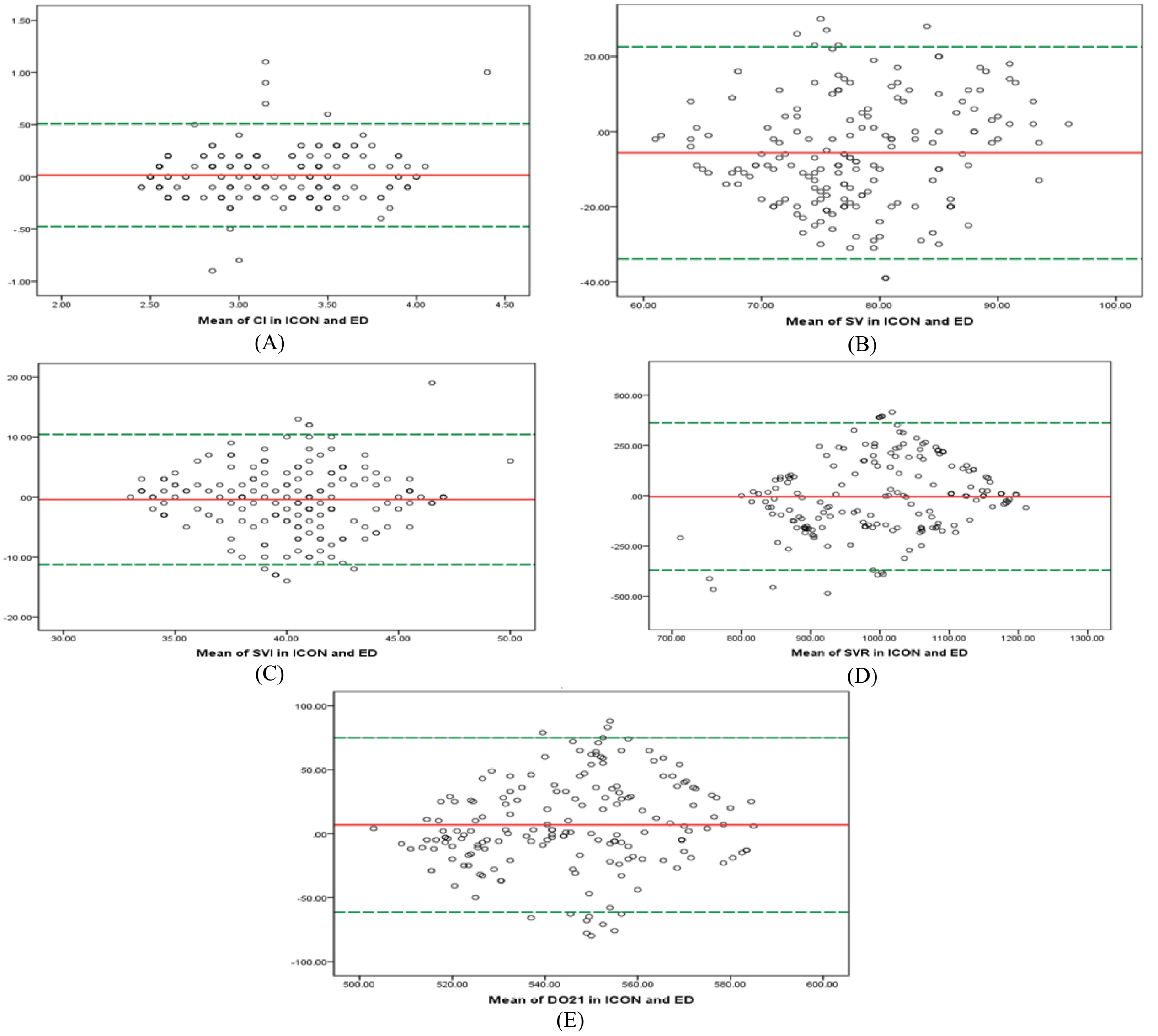
beat) and ED mean value ranged from 38.8 to 42.7 (ml/m^2/beat) with non-significant difference between the two methods at T1, T3 and T4. The precision for the ICON ranged from 7.86 to 12.84% and the precision for ED ranged from 8.86 to 12.41%. Comparison of SVR with ICON and ED showed that The ICON mean value range from 971.1 to 1016.7 (mmHg/min/ml) and ED mean value range from 947.9 to 1072.6 (mmHg/min/ml) with non-significant difference between the two methods at T1, T2, and T4. The precision for the ICON ranged from 13.4 to 18.64% and the precision for ED ranged from 8.41 to 14.93%. %. Comparison of DO_2 I with ICON and ED showed that ICON mean values range from 541.2 to 561.1 (ml O_2/min/m^2) and ED mean values range from 535.1 to 548.9 (ml O_2/min/m^2) with non-significant difference between the two methods at T1, T3 and T4. The precision for the ICON was measured to be ranged from 4.17 to 5.7%, and the precision for ED ranged from 3.39 to 5.04%. Table 3

Figure 2 shows (A) The mean bias was 0.0154, the SD was 0.25, and the limits of agreement were 1.96 times with SD = (−0.478–0.508), (B) The mean bias was −5.66, the SD was 14.41, and the limits of agreement were 1.96 times with SD = (−33.9–22.59), (C) The mean bias was −0.42 with an SD of 5. The agreement limits were 1.96 times with SD = (−11.25–10.42), (D) The mean bias was −4.01, and the SD was 186.53. The agreement limits were 1.96 times with SD = (−369.6–

Table 3. CI (l/min/m^2), SV (ml/beat), SVI (ml/m^2/beat), SVR (mmHg/min/ml), DO_2I (ml O_2/min/m^2) by the two methods among the studied groups at different times of follow-up.

		ICON	ED	Bias	Limits of Agreement	P E	Precision of ICON	Precision of ED	P. value
CI	T1	3.0 ± 0.5	3.0 ± 0.4	−0.01	−0.51–0.49	−58.5	16.25	12.19	0.9 NS
	T2	3.1 ± 0.4	3.2 ± 0.4	−0.04	−0.57–0.49	−13.3	13.40	13.11	0.4 NS
	T3	3.3 ± 0.4	3.2 ± 0.4	0.08	−0.45–0.61	6.4	13.42	13.17	0.08 NS
	T4	3.3 ± 0.5	3.2 ± 0.5	0.04	−0.34–0.41	10.1	14.75	14.99	0.3 NS
	T5	4.9 ± 6.7	3.3 ± 0.5	0.01	−0.46–0.47	82.0	14.07	14.81	0.2 NS
SV	T1	75.7 ± 10.3	77.7 ± 13.5	−2.00	−35.17–31.17	−16.6	13.37	17.06	0.5
	T2	69.6 ± 7.9	82.6 ± 8.9	−13.03	−31.18–5.13	−1.4	11.16	10.59	0.001**
	T3	75.3 ± 7.1	79.0 ± 6.7	−3.69	−22.83–15.45	−5.2	9.23	8.30	0.03*
	T4	77.5 ± 13.6	83.3 ± 10.0	−5.86	−39.15–27.44	−5.7	17.27	11.83	0.04*
	T5	77.6 ± 12.5	81.3 ± 5.0	−3.71	−31.48–24.05	−7.5	15.81	6.03	0.1
SVI	T1	41.4 ± 5.4	40.1 ± 5.1	1.26	−8.37–10.89	7.7	12.84	12.41	0.1
	T2	37.1 ± 3.6	38.8 ± 4.7	−1.74	−9.35–5.86	−4.4	9.59	11.82	0.01*
	T3	39.1 ± 3.4	39.0 ± 3.5	0.09	−9.02–9.19	106.2	8.59	8.86	0.9
	T4	39.5 ± 3.9	42.7 ± 4.0	−3.29	−16.48–9.91	−4.0	9.70	9.21	0.01*
	T5	42.4 ± 3.4	40.8 ± 3.7	1.60	−8.91–12.11	6.6	7.86	9.03	0.09
SVR	T1	971.1 ± 147.5	968.9 ± 146.8	2.11	−445.41–449.64	211.7	14.98	14.93	0.9 NS
	T2	997.1 ± 135.8	986.5 ± 119.4	10.69	−320.75–342.12	31.0	13.42	11.93	0.7 NS
	T3	1016.7 ± 138.3	1072.6 ± 118.3	−55.89	−367.15–255.38	−5.6	13.40	10.87	0.04*
	T4	1002.2 ± 189.5	1020.0 ± 112.8	−17.74	−337.07–301.59	−18.0	18.64	10.90	0.5 NS
	T5	988.7 ± 177.8	947.9 ± 80.9	40.80	−327.65–409.25	9.0	17.73	8.41	0.2 NS
DO_2I	T1	541.2 ± 31.3	539.6 ± 18.5	1.57	−69.63–72.77	45.3	5.70	3.39	0.8 NS
	T2	561.1 ± 23.7	547.1 ± 28.0	13.97	−51.05–78.99	4.7	4.17	5.04	0.02*
	T3	541.7 ± 27.9	541.5 ± 26.6	0.11	−71.48–71.71	626.5	5.08	4.84	0.9 NS
	T4	554.6 ± 25.2	548.9 ± 21.9	5.71	−58.07–69.50	11.2	4.48	3.93	0.3 NS
	T5	547.8 ± 25.5	535.1 ± 21.9	12.66	−51.04–76.35	5.0	4.60	4.04	0.03*

Note: CI: Cardiac Index, SV: Stroke volume, SVI: Stroke Volume Index, SVR: Systemic vascular resistance, DO_2I: Oxygen delivery index.



(A) (B) (C) (D) (E)

Figure 2. Bland Altman analysis of (A) ICONCI and EDCI of CI results, (B) ICONSV and EDSV of SV results, (C) ICONSVI and EDSVI of SVI results, (D) ICONSVR and EDSVR of SVR results, (E) ICONDO$_2$I and EDDO$_2$I of DO$_2$ results.

361.6), and (E) The mean bias was 6.81, the SD was 34.83. The agreement's limits were 1.96 times with SD (−61.45–75.06).

In T1, both methods were correlated positively regarding the reading in CO, CI, and SVI. In T3, both methods were correlated positively regarding the reading in CO, CI. In T4, both methods were correlated positively regarding the reading in CO, CI, and SVR. In T4, there was no significant correlation between the two methods reading in any of the studied parameters. Table 4

4. Discussion

The main findings in the present study showed that at a 15% change in ICON, the ED values' sensitivity was 72.6% and specificity was 30.9% with AUC 0.505. Comparison of CI with ICON and ED showed that ICON mean value ranged from 3 to 4.9 (l/min/m^2) and ED mean value always ranged from 3 to 3.3 (l/min/m2) with non-significant difference between the two methods. Comparison of SV with ICON and ED showed insignificant difference between the two methods at T1 and T5. The precision for the ICON ranged from 15.19 to 17.99% and the precision for ED ranged from 13.39 to 17.08%. In T1, both methods were correlated positively regarding the reading in CO, CI, and SVI. The agreement between CO measured by EC and ED was acceptable.

Among the 23 bioimpedance investigations considered, Critchley and Critchley [9] observed an overall mean CO of 4.8 litre/min. The thermodilution, dye dilution, and the Fick method, which was used primarily in pediatrics, were contrasted with the bioimpedance method. The overall limits of agreement were −1.7 liter/min, while the overall bias from these trials was 0.6 liter/min. For investigations using the bioimpedance approach, the error rate was 37%. They offered standards that made it possible to quantify the allowable ranges of agreement between two CO

Table 4. The studied parameters in the base line time (T1), T3, T4, and T5 by the two methods.

					Intraclass correlation	
		ICON	ED	P. value	Correlation Coefficient	P. value
T1	CO (l/min)	5.6 ± 0.9	5.7 ± 0.8	0.3	0.952	0.001**
	CI ($l/min/m^2$)	3.0 ± 0.5	3.0 ± 0.4	0.9	0.832	0.001*
	SV (ml/beat)	75.7 ± 10.3	77.7 ± 13.5	0.5	−0.03	0.6
	SVI ($ml/m^2/beat$)	41.4 ± 5.4	40.1 ± 5.1	0.1	0.537	0.001*
	SVR (mmHg/min/ml)	971.1 ± 147.5	968.9 ± 146.8	0.9	0.248	0.9
	$DO_2$1 ($ml/min/m^2$)	541.2 ± 31.3	539.6 ± 18.5	0.8	−0.027	0.6
T3	CO (l/min)	6.0 ± 1.0	6.0 ± 0.9	0.4	0.955	0.001**
	CI ($l/min/m^2$)	3.3 ± 0.4	3.2 ± 0.4	0.08	0.789	0.001*
	SV (ml/beat)	75.3 ± 7.1	79.0 ± 6.7	0.03*	−0.04	0.6
	SVI ($ml/m^2/beat$)	39.1 ± 3.4	39.0 ± 3.5	0.9	0.07	0.3
	SVR (mmHg/min/ml)	1016.7 ± 138.3	1072.6 ± 118.3	0.04*	0.201	0.1
	$DO_2$1 ($ml/min/m^2$)	541.7 ± 27.9	541.5 ± 26.6	0.9	0.079	0.3
T4	CO (l/min)	6.2 ± 1.0	6.2 ± 1.1	0.9	0.968	0.001**
	CI ($l/min/m^2$)	3.3 ± 0.5	3.2 ± 0.5	0.3	0.922	0.001*
	SV (ml/beat)	77.5 ± 13.6	83.3 ± 10.0	0.04*	−0.04	0.6
	SVI ($ml/m^2/beat$)	39.5 ± 3.9	42.7 ± 4.0	0.01*	−0.386	0.9
	SVR (mmHg/min/ml)	1002.2 ± 189.5	1020.0 ± 112.8	0.5	0.442	0.004*
	$DO_2$1 ($ml/min/m^2$)	554.6 ± 25.2	548.9 ± 21.9	0.3	0.023	0.4
T5	CO (l/min)	6.2 ± 1.1	7.6 ± 1.04	0.4	−0.003	0.5
	CI ($l/min/m^2$)	4.9 ± 6.7	3.3 ± 0.5	0.2	−0.002	0.5
	SV (ml/beat)	77.6 ± 12.5	81.3 ± 5.0	0.1	−0.14	0.8
	SVI ($ml/m^2/beat$)	42.4 ± 3.4	40.8 ± 3.7	0.09	−0.15	0.8
	SVR (mmHg/min/ml)	988.7 ± 177.8	947.9 ± 80.9	0.2	0.046	0.4
	$DO_2$1 ($ml/min/m^2$)	547.8 ± 25.5	535.1 ± 21.9	0.03*	0.036	0.4

CO: Cardiac output, CI: Cardiac Index, SV: Stroke volume, SVI: Stroke Volume Index, SVR: Systemic vascular resistance, DO_2I: Oxygen delivery index.

measurement approaches. They estimated a −20% measurement error for physiological variables such as CO. For instance, it was determined that the thermodilution technique had a 22% inaccuracy for single measurements. If the standard errors of both methods are comparable to thermodilution CO measurements, a mean error percentage of 30% between two procedures is clinically acceptable. The test and standard method errors can be combined using a program.

Ibrahim et al. [10], in contrast to our investigation, discovered that EC CO was consistently higher than TED CO (l/min). This could be explained by the fact that the TED probes were placed with their backs to the descending aorta, which could have underestimated CO because there was no blood flow to the brain or upper extremities there.

A possible explanation for the consistently lower TED CO values than EC CO reported at all measuring points was the position of the TED probes in the lower esophagus facing the descending aorta, which may underestimate the CO because cerebral and upper limb blood flows are absent from this part of the aorta.

Additionally, Knirsch et al. [11] reported that during heart catheterization of 40 paediatric cases with congenital heart abnormalities, the CO measured by the TED probes was lower than that measured using the pulmonary artery catheter thermodilution approach. To enhance the accuracy of TED CO readings, they recommended measuring the unique aortic diameter of each paediatric patient rather than relying on general population nomograms that had already been generated.

According to Monnet et al. [12], one of the main causes of mistake in TED CO measurements can be the aortic cross-sectional area. To overcome errors, TED substitutes the observed minute distance (= time velocity integral multiplied by HR) in the descending aorta for the cross-sectional area. The absolute values of TED CO, however, were less acceptable. Variations in CO as measured by the thermodilution method correlated with variations in the minute distance of TED. The accuracy of TED might be increased by measuring the actual aortic diameter rather than the computed norm gramme constant.

In newborns and babies without cardiac dysfunction, Raux et al. [13] found that the TED-derived SV measures taken during volatile anaesthesia are beneficial for predicting and monitoring volume expansion responsiveness when their indexed stroke volume increased by more than 15%.

ICON-CO and EDCO of CO results showed that mean bias was −0.0257 with SD = 0.39751. Limits of agreement were 1.96 times the SD = −0.68–0.81, and the percentage error (PE) ranges from −126.5% − 14.6%.

Regarding CI, Cox et al. [7], showed that the CI varied between 0.8 and 5.6 (CIBIO) and 1.2 and 7.6 Lmin-1 (CIDOP). CIBIO and CIDOP were significantly different at each point.

Concerning Bland Altman analysis of ICONCI and EDCI of CI results, mean bias was 0.0154 with SD = 0.25. The limits of the agreement were 1.96 times the SD = (−0.478–0.508). Cox et al. [7] showed that some agreement might be present at CI values between approximately 1.6 and 2.7 liter/min/m2. At higher CI values, the spread in the differences between CIBIO and CIDOP rapidly increases, especially at T1 (after induction and prior to incision), and T4 (30 minutes after arrival in the ICU).

Regarding SV, the ICON mean value ranged from 69.6 to 77.6 (ml/beat) and ED mean value ranged from 77.7 to 83.3 (ml/beat) with non-significant difference between the two methods at T1 and T4. The precision for the ICON ranged from 9.23 to 17.27% and for ED ranged from 6.03 to 17.06%.

Regarding SVI, the ICON mean value ranged from 37.1 to 42.4 (ml/m^2/beat) and ED mean value ranged from 38.8 to 42.7 (ml/m^2/beat) with non-significant difference between the two methods at T1, T3 and T4. The precision for the ICON ranged from 7.86 to 12.84% and for ED ranged from 8.86 to 12.41%.

Lotfy et al. [6] monitored and compared values of CO obtained from EC to TED. All pairs of measurements taken at different periods showed a negative association in the SVV (%) of EC Scattered Plot graph.

Our study showed no significant difference between the two methods at T1 in all parameters. Both methods correlated positively regarding the reading in CO, CI, and SVI. But, at T3, there was no significant difference between the two methods in CI, SVI, and DO$_2$I. Both methods were correlated positively regarding the reading in CO and CI. At T4, there was no significant difference between the two methods in CI, SVI, and DO$_2$I. Both methods were correlated positively regarding the reading in CO, CI, and SVR. Also, at T4, there was no significant difference between the two methods in CI, SV, SVI, and SVR, and there was no significant correlation between the two methods reading in any of the studied parameters.

A reasonable level of concordance between EC and the continuous thermodilution CO was shown by Rajput et al. [14]. EC and transthoracic echocardiography have an excellent agreement for calculating left ventricular stroke volume. Therefore, when invasive procedures need to be avoided or are not available, EC can be utilized to assess hemodynamic variables in cardiac surgery cases.

In contrary, Magliocca et al. [15] showed that non-invasive CO estimation with EC exhibited limited accuracy and precision, particularly as SVR decreased, but the CO values during surgery exhibited a reasonable ability to trend when compared to the thermodilution technique (TDT) CO measurement. Using thermodilution during cardiopulmonary bypass and moderate hypothermia during cardiac surgery revealed a lack of agreement between the two types of CO measurements.

Dubost et al. [16] compared the monitoring performance of electrical bioreactance to the TED in pediatric population and came to the conclusion that CO measured simultaneously by bio reactance and TED can be of a high percentage of variability.

According to Srivastava et al. [17], the use of TED may replace invasive central line insertions and FTc-guided intraoperative fluid treatment yielded the same rate of immediate graft function as CVP-guided fluid therapy.

Narula et al. [18] found that with a significant intraclass Correlation Coefficient (ICC) of 0.78, 50 pediatricians were able to accurately describe the measured CO values by the EC.

Limitation: This study provided the impression that SV did not respond to fluid boluses during perioperative data collection. However, the purpose of this study was not to examine the hemodynamic effects of goal-directed therapy; hence, these findings were not reported in the results.

5. Conclusions

The agreement between CO measured by EC and ED is acceptable. Both monitored trend changes in the operation theater. The EC is as accurate as ED in measuring hemodynamics during major abdominal surgery. It can offer clinically acceptable accuracy for CO assessments. The procedure just calls for the use of common ECG electrodes and doesn't require a skilled operator. It gives a continuous beat-to-beat measurement of CO over an arbitrary long length of time and is non-invasive.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Shady Rady Abdalla, Ahmed Salah Abdelazeem and Tarek Abdelhalium Kaddah. The first draft of the manuscript was written by Abla Salah Elhadedy, Hanan Farouk Khafagy, Ahmed Abdalla Mohamed and Ahmed Mohamed Essam. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

ORCID

Shady Rady Abdalla http://orcid.org/0000-0001-5391-8569

Sponsors and funding sources

This research did not receive any specific grant from any funding agency in the public, commercial, or not-for-profit sector.

References

[1] Bellofiore A, Chesler NC. Methods for measuring right ventricular function and hemodynamic coupling with the pulmonary vasculature. Ann Biomed Eng. 2013;41 (7):1384–1398.

[2] Salmasi V, Maheshwari K, Yang D, et al. Relationship between intraoperative hypotension, defined by either reduction from baseline or absolute thresholds, and acute kidney and myocardial injury after noncardiac surgery: a retrospective cohort analysis. Anesthesiology. 2017;126(1):47–65. DOI:10.1097/ALN.0000000000001432

[3] Abdelhafez HS, Yassen KA, El Sahn FF, et al. Transesophageal Doppler corrected flow time versus plethysmography variability index for goal-directed fluid management in cirrhotic patients during liver resection: a randomized controlled trial. Ain Shams J Anesth. 2022;14(1):89.

[4] El Sharkawy OA, Refaat EK, Ibraheem AE, et al. Transoesophageal Doppler compared to central venous pressure for perioperative hemodynamic monitoring and fluid guidance in liver resection. Saudi J Anaesth. 2013;7(4):378–386. DOI:10.4103/1658-354X.121044

[5] Siedlecka J, Siedlecki P, Bortkiewicz A. Impedance cardiography – Old method, new opportunities. Part I. Clinical applications. Int J Occup Med Environ Health. 2015;28:27–33.

[6] Lotfy M, Yassen K, El Sharkawy O, et al. Electrical cardiometry compared to transesophageal Doppler for hemodynamics monitoring and fluid management in pediatrics undergoing Kasai operation. A randomized controlled trial. PACCJ. 2018;6.

[7] Cox P, den Ouden A, Theunissen M, et al. Accuracy, precision, and trending ability of electrical cardiometry cardiac index versus continuous pulmonary artery thermodilution method: a prospective, observational study. BioMed Res Int. 2017;2017:1–8.

[8] Elgebaly AS, Anwar AG, Fathy SM, et al. The accuracy of electrical cardiometry for the noninvasive determination of cardiac output before and after lung surgeries compared to transthoracic echocardiography. Ann Card Anaesth. 2020;23(3):288.

[9] Critchley LA, Critchley JA. A meta-analysis of studies using bias and precision statistics to compare cardiac output measurement techniques. J Clin Monit Comput. 1999;15(2):85–91.

[10] Ibrahim ES. Comparison of electrical cardiometry and trans esophageal Doppler for hemodynamics monitoring during living donor liver transplantation: a randomized controlled trial. EC Anaesth. 2019;5:81–91.

[11] Paediatrics: WGoN-iHMi, Knirsch W, Kretschmar O, Comparison of cardiac output measurement using the CardioQP TM oesophageal Doppler with cardiac output measurement using thermodilution technique in children during heart catheterisation. Anaesthesia. 2008;63(8):851–855.

[12] Wodey E, Gai V, Carre F, et al. Accuracy and limitations of continuous oesophageal aortic blood flow measurement during general anaesthesia for children: comparison with transcutaneous echography-Doppler. Paediatr Anaesth. 2001;11(3):309–317.

[13] Raux O, Spencer A, Fesseau R, et al. Intraoperative use of transoesophageal Doppler to predict response to volume expansion in infants and neonates. Br J Anaesth. 2012;108(1):100–107. DOI:10.1093/bja/aer336

[14] Rajput RS, Das S, Chauhan S, et al. 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(07):123–130.

[15] Magliocca A, Rezoagli E, Anderson TA, et al. Cardiac output measurements based on the pulse wave transit time and thoracic impedance exhibit limited agreement with thermodilution method during orthotopic liver transplantation. Anesth Analg. 2018;126(1):85–92.

[16] Dubost C, Bouglé A, Hallynck C, et al. Comparison of monitoring performance of bioreactance versus esophageal Doppler in pediatric patients. Indian J Crit Care Med. 2015;19(1):3–8. DOI:10.4103/0972-5229.148630

[17] Srivastava D, Sahu S, Chandra A, et al. Effect of intraoperative transesophageal Doppler-guided fluid therapy versus central venous pressure-guided fluid therapy on renal allograft outcome in patients undergoing living donor renal transplant surgery: a comparative study. J Anesth. 2015;29(6):842–849.

[18] Narula J, Chauhan S, Ramakrishnan S, et al. Electrical cardiometry: a reliable solution to cardiac output estimation in children with structural heart disease. J Cardiothorac Vasc Anesth. 2017;31(3):912–917.