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Validation of Electrical Cardiometry Measurements Compared to Transthoracic Echocardiography in Fluid Responsiveness in Sepsis

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: Severe sepsis and septic shock patients have a broad range of hemodynamic characteristics. A better understanding of the hemodynamic profile and response to therapy can lead to more effective treatment and consequently a lower mortality and morbidity. The current research work was designed to investigate the non-invasive diagnostic accuracy and agreement of electrical cardiometry (EC) with transthoracic echocardiography (TTE) for fluid responsiveness in sepsis.
Methods: This prospective cohort study was assessed on 25 patients showing clinical criteria of sepsis and developed hypotension. All patients were subjected to simultaneous measurement by EC and TTE. Fluid was administered if stroke volume (SV) measured by TTE increased by > 10% after the fluid challenge up to 30 mL/kg else vasopressor infusion was initiated.
Results: Electrical cardiometry significantly predicted fluid responsiveness in sepsis compared to TTE with 81.4% sensitivity and 90% specificity. There was an insignificant difference between SV index (SVI), cardiac index (CI), SV, and cardiac output (CO) estimated by TTE and by EC. The mean bias between SV measured by TTE and by EC was 0.25 ± 3.4 ml. The mean bias between TTE and by EC was 0.10 ± 1.78 mL/m^2 in SVI, 0.01 ± 0.35 L/min in CO and 0.009 ± 0.18 L/min/m^2 in CI.

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Conclusions: Electrical cardiometry significantly predicted fluid responsiveness in sepsis compared to TTE with good agreement between measurements of EC and TTE.

Keywords: Sepsis; fluid responsiveness; electrical cardiometry; transthoracic echocardiography.

1. INTRODUCTION

Sepsis and septic shock are significant disorders that influence millions of individuals around the world each year. Early detection and early management of sepsis enhance better outcomes [1].

Fluid administration is a critical aspect of supportive treatment for sepsis [2]. In consideration of the risks of both over-and under-resuscitation, it is critical to distinguish individuals who will get benefit from more intravenous fluid treatment after boluses of intravenous fluid. Some of the hemodynamic characteristics of patients with septic shock and severe sepsis are very different from one another. A better or clearer understanding of the hemodynamic profiles in septic shock as well as the response to therapy may well lead to outcomes of reduced mortality and morbidity in the patients concerned [3].

The ultimate hemodynamic monitor should be safe, affordable, non-invasive, simple, and capable of continuous, hands-free data acquisition [4] The gold standard for measuring stroke volume (SV) is intermittent pulmonary artery catheter (PAC) thermodilution. However, these procedures are invasive and have been associated with health challenges [5].

Transthoracic echocardiography (TTE) is considered the popular non-invasive method; however, it has significant limitations due to the need for a skilled operator, is technically challenging, and is achieved on an intermittent basis [6].

Electrical cardiometry (EC) may constantly and non-invasively measure cardiac output (CO) based on thoracic electrical bioimpedance. During the cardiac cycle, the CO assessment is performed by thoracic electrical impedance utilizing the EC strategy that was influenced by erythrocyte orientation and the peak flow velocity in the ascending aorta [7].

The study was conducted to validate EC use for the non-invasive determination of fluid responsiveness compared to TTE in a special category of critically ill patients in whom dynamic fluid responsiveness is of clinical value in the management.

2. PATIENTS AND METHODS

In our prospective cohort observational study, 25 patients aged 19 to 65 years old, of both sexes, with clinical criteria for sepsis and hypotension (mean arterial pressure (MAP) ≤ 65 mmHg) were included. Sepsis was diagnosed by a 2 point elevation in the Sequential Organ Failure Assessment (SOFA) score [8] variables resulting from the infection.

The patients or their relatives were requested for written informed consent. Patients with shock for any other reason, preexisting cardiac illness, heart rate greater than 140 beats/min, rhythm other than sinus rhythm, chronic renal failure, and morbid obesity were excluded.

The following investigations were done [complete blood count, C- reactive protein, procalcitonin, serum lactate, liver, and renal function tests, arterial blood gases, electrocardiogram, and blood culture].

Patients with definitively diagnosed sepsis and experienced hypertension underwent simultaneous EC and TTE measurements. Sepsis was managed based on the surviving sepsis campaign guidelines in 2016 [9] and its update 2018 [10]. Fluid resuscitation consisted of a 30 ml/kg lactated ringer IV infusion given over the first 3 hours (5 mL/kg/30 min) and was monitored by fluid receptiveness[11] (the patient was considered a fluid responder if SV evaluated by TTE rises by more than 10% following the fluid replacement [11]. If the patient fails to respond to fluids, the infusion of vasopressor (0.05–0.3g/kg/min norepinephrine) was initiated.

2.1 Electrical Cardiometry

Measurements were performed using an ICON ® Hemodynamic Monitoring System (ICON Cardiotronics, Inc., La Jolla, CA 92307; Osyka Medical GmbH, Berlin, and Germany, model C3, Serial no: 1725303). There were four EC sensors used as follows (1st: 5 cm from the base of the

neck, 2nd: on the base of the neck, 3rd: lower thorax at xiphoid process level, and 4th: 5 cm down the 3rd electrode at anterior axillary).

2.2 Transthoracic Echocardiography

Measurements were carried out using Philips ® (CX50 – Extreme edition) prepared with phased array transducer. The patient was in the supine position.

SV of the left ventricle was estimated through:

(a) Left Ventricular Outflow Tract (LVOT) diameter in the parasternal long-axis view was measured at the aortic annulus at the base of the leaflets after the screen is frozen at the best aortic valve view during mid-systole.

(b) Left ventricular outflow tract velocity time integral (LVOT VTI): at the apical five-chamber view, we visualized LVOT and the aortic valve. Next, the pulse wave Doppler gate was placed at the LVOT at the aortic annulus or the base of the aortic valve leaflets. VTI tracing was improved by integrating the pulse wave Doppler gate and LVOT as close together as feasible. Then, the outline of one of the systolic waveforms was frozen and traced.

At the same previous view of PW Doppler, we just moved the cursor from one peak of a wave to another, and the machine calculated the HR and CO automatically.

MAP and TTE and EC measurements [SV, cardiac output (CO), cardiac index (CI), and stroke volume index (SVI)] were recorded immediately earlier the fluid resuscitation and every 30 min till MAP > 65 mmHg.

The primary outcome was the diagnostic accuracy of EC in predicting fluid responsiveness. The secondary outcomes were agreements of measurements of EC with TTE.

2.3 Sample Size Calculation

The sample size was computed by MedCalc ® programme version 18.2.1 (MedCalc Software, Ostend, Belgium) as at least 21 patients (at least 7 fluid responder and at least 14 fluid non-responder). The sample size was determined using the subsequent criteria: 0.05 alpha error and a power of 99%. Depending on a prior study [12], the area under the curve (AUC) for EC's ability to predict fluid responsiveness was 0.927, and the ratio of fluid non-responders to responders was 2:1.

2.4 Statistical Analysis

SPSS v25 (IBM Inc., Chicago, IL, USA) was utilized for statistical analysis. The mean and standard deviation (SD) described the quantitative data, whereas the frequency and percentage (%) described the qualitative variables. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were used to clarify the diagnostic performance. Agreement: a) Measurements of TTE and EC were compared by paired Student's T test b) Modified Bland Altman plots of TTE and EC measurements were done to calculate the bias and its SD. A two-tailed P value < 0.05 was considered significant.

3. RESULTS

Table 1 shows the patient characteristics and laboratory data of the studied patients.
Mean arterial blood pressure changes for all included subjects are shown in Fig. 1.

SV and SVI changes measured by TTE and EC for all participants are shown in Fig. 2.

CO and CI changes measured by TTE and EC for all participants are shown in Fig. 3.

EC significantly predicted fluid responsiveness in sepsis compared to TTE with 81.4% sensitivity, 90% specificity, 96.6% PPV, and 58.1% NPV.

There was an insignificant difference between SVI, SV, CO, and CI measured by TTE and by EC. Table 2.

The mean bias between SV measured by TTE and by EC was 0.25 ± 3.4 mL. The mean bias between SVI measured by TTE and by EC was 0.10 ± 1.78 mL/m^2. The mean bias between CO measured by TTE and by EC was 0.01 ± 0.35 L/min. The mean bias between CI measured by TTE and by EC was 0.009 ± 0.18 L/min/m^2. Fig. 4.

4. DISCUSSION

Stroke volume may be constantly and non-invasively measured via EC, which utilizes thoracic electrical bioimpedance. The EC

principle uses variations in thoracic electrical impedance that is primarily driven by erythrocyte orientation and peak flow velocity in the ascending aorta over the cardiac cycle to estimate SV [13].

In our study, EC significantly predicted fluid responsiveness in sepsis compared to TTE. This was in agreement with Soliman [12], who showed that cut-off 12.5% for delta CO by TTE for prognosis the fluid receptiveness in severe sepsis and hypotension patients with sensitivity 90%, and specificity 70%. However, they did not compare EC with TTE as in our study.

Also, Rajput et al. [14] found that ROC curve between EC and thermodilution by PAC with a cut-off of 15% demonstrates a sensitivity of 84% and specificity of 63% in cardiac surgical patients.

As compared to thermodilution, transesophageal Doppler echocardiography, and cardiac catheterization, EC has been proven to guide CO and other hemodynamic parameters non-invasively, including critically ill patients [15,16], intraoperative settings [14], pregnant women[17], children with congenital heart disease [18], and obese children [19].

Our results were in line with Elgebaly et al. [20] who reported that the mean bias(limits of agreement) of CO between EC and TTE was 0.01 (–0.68 to 0.70) at preoperative readings but was –0.01 (–1.21 to 1.18) at postoperative readings in patients with age ≥18 years scheduled for elective lung surgery.

Also, Malik et al. [21] studied patients requiring PAC implantation by coronary artery surgery. Contemporary CO measurements from EC and thermodilution by PAC were completed at three predetermined time intervals and correlated with one another. There was a bias of 0.08 L/min, a precision of 0.15 L/min, with a slight limit of agreement (-0.13 to 0.28 L/min), and the percentage error was 3.59%. They determined that the CO agreement between EC and thermodilution by PAC is clinically accepted and could be applied mutually.

Our results agreed with Schmidt et al., [22] who showed that the mean bias (limits of agreement) in CO between EC and TEE was 0.18 (-0.99 to 1.36 l/min) patients planned for coronary artery surgery necessitating TEE monitoring.

Table 1. Patients characteristics and laboratory investigations of all subjects (n = 25)

Patient characteristics		
Age (years)		44.76 ± 9.18
Sex	Male	13 (52%)
	Female	12 (48%)
BMI (kg/m^2)		29.32 ± 4.51
		Laboratory investigations
Hb (gm/dL)		10.96 ± 1.62
Platelet count (*10^3 cells/dL)		257.6 ± 71.02
TLC (*10^3 cells/dL)		15.12 ± 1.79
CRP (mg/L)		82.08 ± 21.65
Lactate (mmol/L)		3.89 ± 1.31
pH		7.22 ± 0.07
PaO_2 (mmHg)		101.92 ± 10.48
$PaCO_2$ (mmHg)		31.88 ± 3.32
HCO_3 (mEq/L)		13.2 ± 2.8

Data are presented as mean ± SD or frequency (%). BMI: Body mass index, Hb: hemoglobin, TLC: total leucocytic count, CRP: C-reactive protein, PaO_2: arterial oxygen tension, $PaCO_2$: carbon dioxide tension

Table 2. Difference between SV (mL), SVI (mL/m^2), CO (L/min) and CI (L/min/m^2) measured by transthoracic echocardiography and by electrical cardiometry (EC)

	Measured by TTE	**Measured by EC**	**P value**
SV	77.12±15.88	77.92±15.82	0.703
SVI	40.03±8.63	40.44±8.59	0.717
CO	8.23±1.45	8.33±1.48	0.620
CI	4.26±0.75	4.31±0.76	0.622

SV: Stroke volume, SVI: Stroke volume index, CO: Cardiac output, CI: Cardiac index

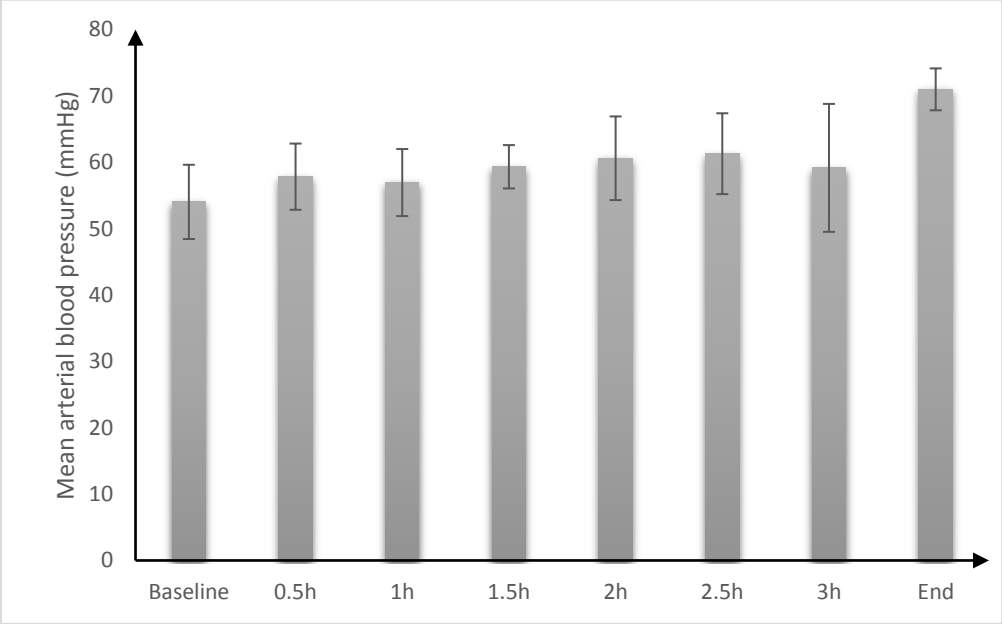

Fig. 1. Mean arterial blood pressure (mmHg) variations of the studied patients

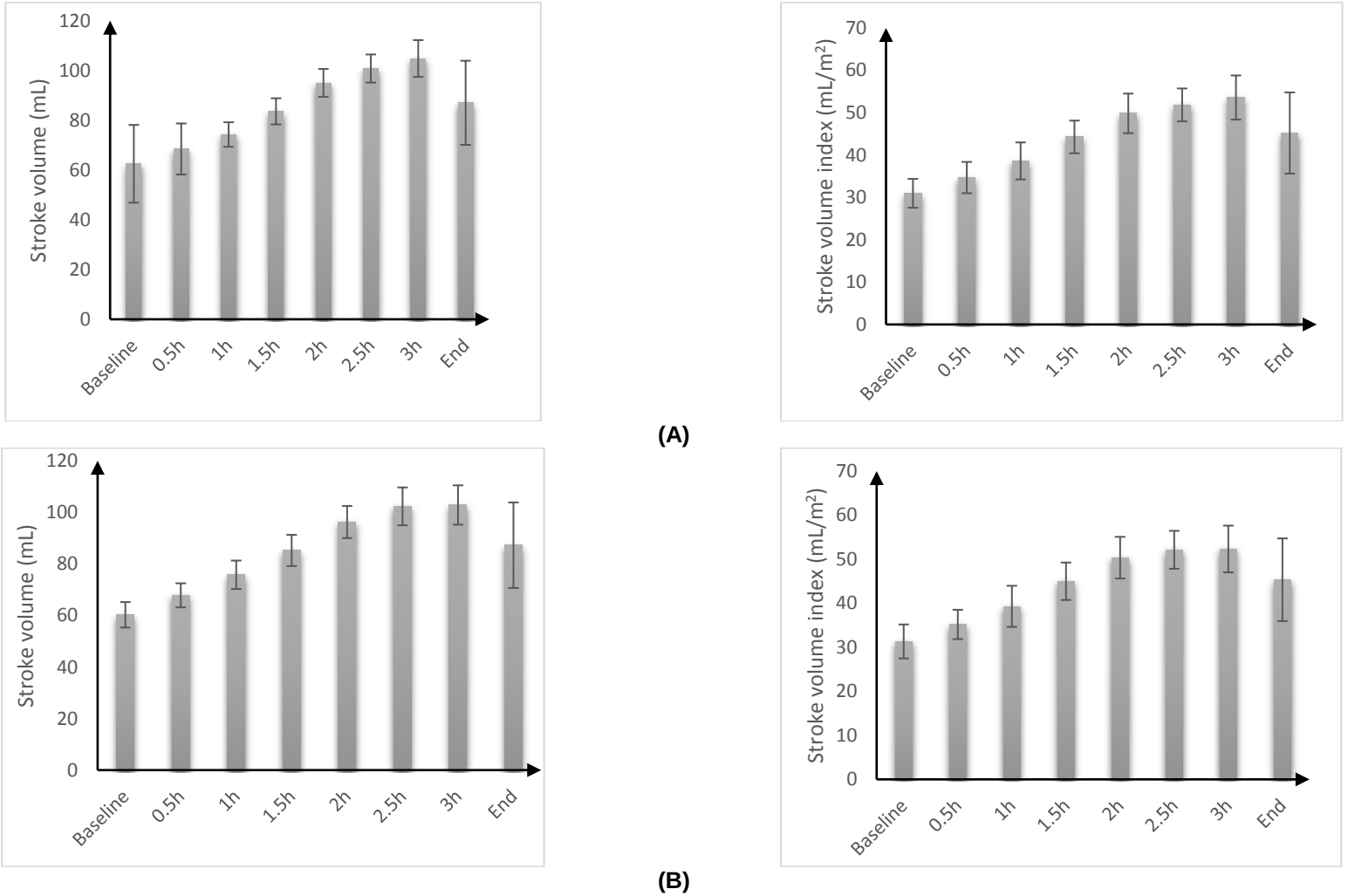

Fig. 2. Stroke volume and stroke volume index changes measured by (A) transthoracic echocardiography and by (B) electrical cardiometry of the studied patients

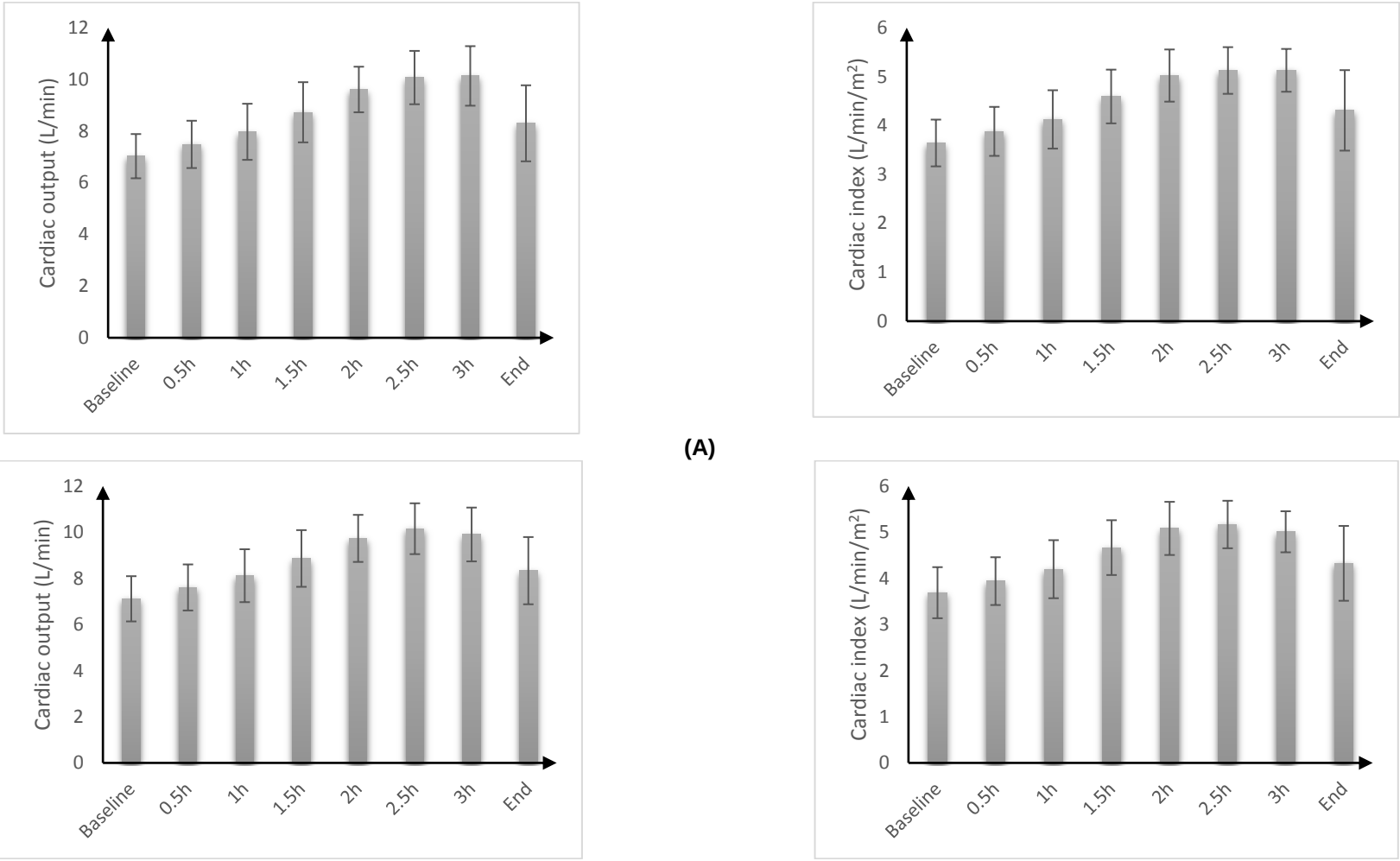

Fig. 3. Cardiac output and cardiac index changes measured by (A) transthoracic echocardiography and (B) electrical cardiometry of the studied patients

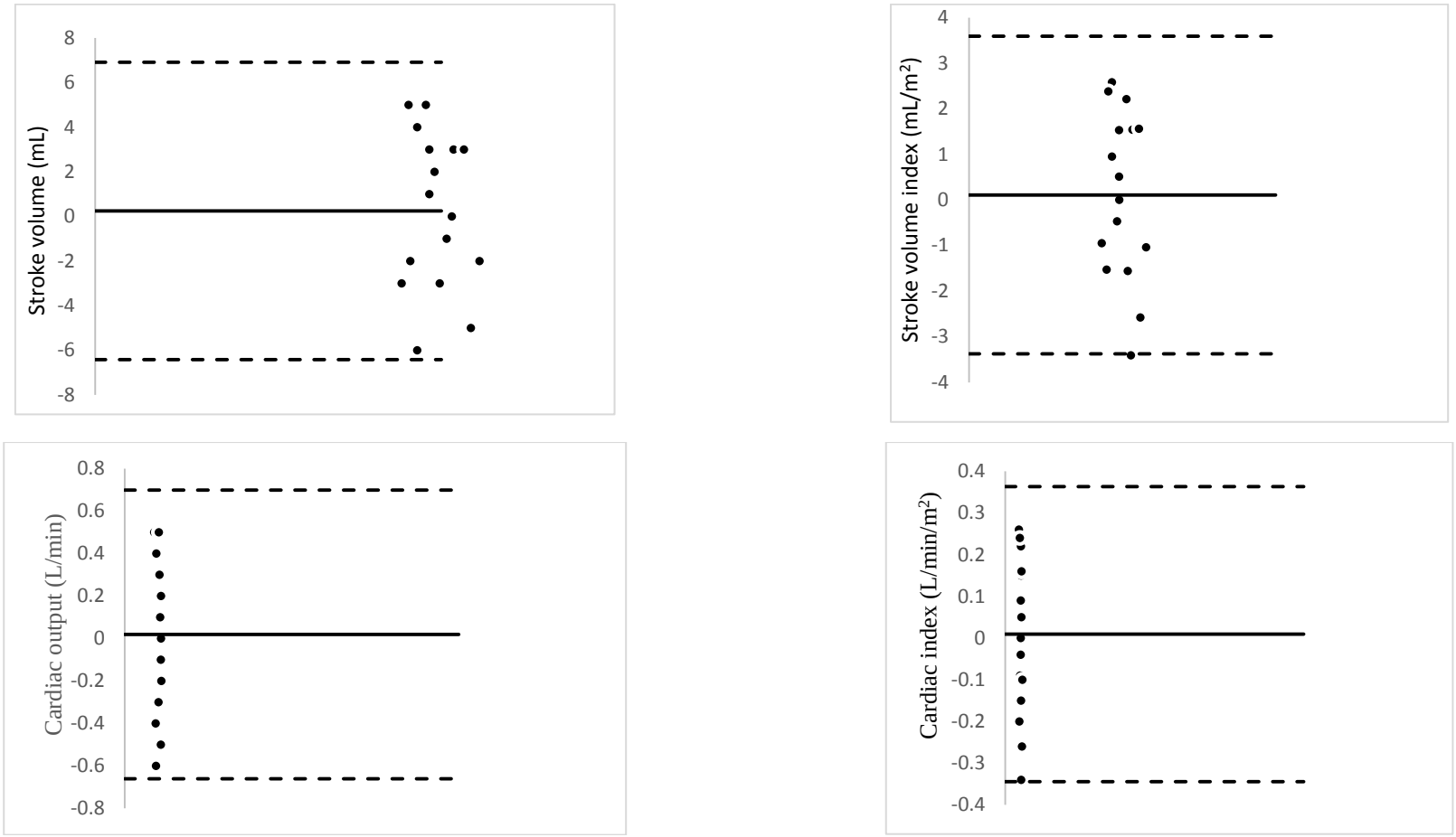

Fig. 4. (A) Agreement between stroke volume, (B) stroke volume index, (C) cardiac output and (D) cardiac index measured by transthoracic echocardiography and by electrical cardiometry

In disagreement with our results, Magliocca et al. [23] compared CO estimation by EC with thermodilution by PAC on patients underwent orthotopic liver transplantation (OLT) at 5-time points: (T1) PAC insertion; (T2) surgical incision; (T3) portal reperfusion; (T4) hepatic arterial reperfusion; and (T5) abdominal closure. The mean bias (±SD) of EC was −3.3 L/min (±2.8 L/min), and the percentage error was 77%. They revealed that EC had less accuracy and precision than thermodilution during OLT, despite its good trending ability. This difference may be due to the different types of patients (OLT in their study). The inaccuracy of EC is specifically large when SVR and arterial elastance were diminished throughout the neohepatic phase.

Our results were contrary to those of Martin et al. [17], who validated EC in pregnant patients compared to TTE on 44 non-laboring, resting pregnant women. SV by EC had a mean bias of -0.83 mL and a mean percentage error of 22% compared to TTE. They concluded that the bias and mean percentage error of SV and CO were excessively high. This difference may be due to the different populations (pregnant women in their study).

Moreover, Raue et al. [24] indicated that the mean bias in CO measured concurrently by EC and thermodilution PAC was -0.3 l/min in patients with sepsis with hemodynamic instability or severe systemic inflammatory response syndrome, with frequent limits of agreement (-4.1:3.5 l/min). They concluded that EC could not replace PAC. This difference may be due to different hemodynamic conditions [most patients were on inotropic support (90%) and on mechanical ventilation (96.7%)].

Mekis et al. [25] results were in contrast to our results. CO levels were determined concurrently with EC and thermodilution PAC in patients prior to and shortly following coronary artery bypass graft surgery, as well as in the ICU. The agreement was clinically acceptable only before skin incision (mean bias was 0.04 ± 0.41 L/min, and the mean error was 25%) while it was unacceptable immediately following skin closure (the mean bias was 0.57 ± 0.92 L/min, and the mean error was 42%) and at a borderline level in the ICU (the mean bias was 0.26 ± 0.68 L/min, and the mean error was 32%). Thus, the overall accuracy is not clinically unacceptable. In their study, the thoracic fluid index recorded a statistically significant elevation, whereas the hemoglobin showed an immediate significant drop subsequent to skin closure. Also, this could be due to thermal noise' rises following cardiopulmonary bypass [26].

Moreover, Heringlake et al. [27] showed a bias in CO between PAC and EC of −0.4 L/min and 0.4 L/min and a precision of 3.2 and 3.6 L/min (34.3% and 67.4%) after anesthesia and ICU admission, respectively in patients undergoing elective cardiac surgery with cardiopulmonary bypass and moderate hypothermia. This difference may be due to the different types of patients in their study.

Limitations: The sample size was relatively limited. The study was in a single center. The follow-up of patients was limited for a relatively short period. We excluded rhythm other than sinus rhythm or HR > 140 beats/min, chronic renal failure, and earlier cardiac disease. We didn't evaluate the role of hypothermia in bias between the two techniques.

CONCLUSIONS

Electrical cardiometry significantly predicted fluid responsiveness in sepsis compared to TTE with 81.4% sensitivity, 90% specificity, 96.6% PPV, and 58.1% NPV. Measurements of EC showed good agreement with measurements of TTE.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

CONSENT AND ETHICAL APPROVAL

Our research work was done after the Ethical Committee approval from Tanta University Hospitals (approval code: 33017/03/19) and registration of clinicaltrials.gov (ID: NCT03938220).

As per international standard or university standard, patients' written consent has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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