

# The Accuracy of Electrical Cardiometry for the Noninvasive Determination of Cardiac Output before and after Lung Surgeries Compared to Transthoracic Echocardiography

## Abstract

**Background:** The anatomical changes associated with lung surgeries may decrease cardiac output and heart function. Therefore, monitoring of cardiac output (CO) is of significant value in these patients for clinical decision-making. **Objective:** This study is to evaluate the reliability of electrical cardiometry (EC) for the noninvasive continuous determination of CO after lobectomy or pneumonectomy compared to transthoracic echocardiography (TTE). **Patients and Methods:** This study was carried out on 60 patients, age  $\geq 18$  years scheduled for elective lung surgery (lobectomy or pneumonectomy). All patients underwent simultaneous measurement by EC using the ICON\_ device and by TTE by measuring left ventricle outflow tract diameter (LVOT) and velocity time integral (VTI). Heart rate (HR), systolic and diastolic blood pressure (SBP and DBP), stroke volume (SV), stroke volume index (SVI), CO, and cardiac index (CI) were measured 1 day before the surgery and 7 days after the surgery. **Results:** There was no significant difference between TTE and EC regarding preoperative and postoperative HR, SV, SVI, CO, and CI. There was a strong positive correlation between TTE and EC as regard preoperative and postoperative HR, SV, SVI, CO, and CI. Bland and Altman analysis showed low bias with accepted limits of agreement of HR, SV, SVI, CO, and CI. Postoperative readings showed a significant increase in HR and a significant decrease in SV and CO (either by TTE or EC), SBP, and DBP as compared to preoperative reading. **Conclusion:** Compared to the TTE, EC provides accurate and reliable CO, SV, and HR measurements before and even after lung surgeries.

**Keywords:** Cardiac output, electrical cardiometry, lung surgery, transthoracic echocardiography

## Introduction

CO monitoring was limited to ICU patients because of its invasiveness and complexity. The ideal CO monitor would be safe, low-cost, painless, noninvasive, easy to use and interpret and allow for the continuous, hands-free acquisition of accurate data. EC, impedance cardiography, has the criteria for an ideal CO monitor. Some disadvantages of TTE include the need for expensive, bulky equipment, and advanced training to obtain accurate VTI with non-continuous acquisition of data.<sup>[1,2]</sup>

Lung surgeries (lobectomy or pneumonectomy) and thoracotomy cause some physiological changes.<sup>[3-5]</sup> Cardiac dysfunction is found after resection because of the resection or the primary pulmonary cause.<sup>[6]</sup> The loss of the pulmonary vasculature after resection can increase the precapillary resistance and can cause

pulmonary hypertension, which can have an effect on the right heart.<sup>[7]</sup> The CO and SV are decreasing, the peripheral arterial pressure and vascular resistance increases and the oxygen saturation at exertion decreases.<sup>[8]</sup> That is why the study of the heart-lung hemodynamics and assessing cardiac function after lung resection is of significant value in patient management.

The aim of this study is to evaluate the reliability of EC for the noninvasive continuous determination of CO after lobectomy or pneumonectomy compared to TTE.

## Patients and Methods

This prospective cohort study was carried out in Tanta University Hospitals from January 2017 to November 2018 on 60 patients scheduled for elective lung surgery (lobectomy or pneumonectomy),

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age  $\geq 18$  years with preoperative sinus rhythm (by ECG), and normal pulmonary artery pressure, right ventricle dimensions, and ejection fraction of the left ventricle (EF) 55% or more (by echocardiography).

All patients received an explanation for the purpose of the study, and written informed consent was taken from each patient participating in the study. The exclusion criteria were respiratory failure, preoperative and postoperative arrhythmia, pericardial effusion, preoperative pulmonary hypertension, congestive heart failure, cardiomyopathy and coronary artery disease, BMI  $>40$  kg/m<sup>2</sup>, preoperative clinical or echocardiographic evidence of valvular heart disease and previous open-heart surgery.

For all patients, thoracotomy incision (posterolateral) and one-lung ventilation were done either in lobectomy or pneumonectomy.

All patients underwent simultaneous measurement by EC using the ICON\_ device and by TTE 1 day before the surgery and 7 days after the surgery.

**Electrical cardiometry measurements:** By the ICON\_ hemodynamic monitor (ICON Cardiometrics, Inc., La Jolla, CA 92307; Osyka Medical GmbH, Berlin, and Germany, model C3, serial no: 1725303). Four sensors of EC were applied (1<sup>st</sup>: 5 cm above the base of the neck, 2<sup>nd</sup>: on the base of neck, 3<sup>rd</sup>: lower thorax at the level of the xiphoid, and 4<sup>th</sup>: 5 cm below the 3<sup>rd</sup> electrode at the level of anterior axillary line). The ICON\_ continuously displays a moving average (obtained from 10 cardiac cycles deemed valid by the monitor) of HR, SV, and CO. The ICON\_ records these and other averaged measured parameter values every 60s.

**Transthoracic echocardiography measurements:** TTE measurements were performed by a single trained cardiac sonographer, who was blinded to the result of EC, using Philips (CX50-extreme edition, serial no: BBOYKF2) equipped echo transducer. SV of the left ventricle was calculated using LVOT diameter (D) just below the aortic valve from parasternal long-axis view and VTI measured in LVOT from apical view (by pulsed wave Doppler), respectively. The machine's built-in software uses the formula " $(\pi D^2/4) \times VTI \times HR$ " to calculate CO.

The primary outcome was the agreement of CO measurement between TTE and EC. Secondary outcomes were the correlation and agreement with HR, SV, SVI, and CI between TTE and EC.

Using MedCalc program version 18.2.1 (MedCalc Software, Ostend, Belgium), the sample size was calculated as 60 patients with 0.1 L/min expected mean of difference in CO between TTE and EC, 0.5 expected SD of difference, and 1.5 L/min maximum allowed difference between TTE and EC with 95% power of study and an alpha error of 0.05 (two tails).

## Statistical analysis

Parametric data were presented as a mean and standard deviation (SD) and analyzed using Student's t test, whereas categorical data were presented as frequency and percentage.

Interchangeability or equivalence between EC and TTE was evaluated by Pearson correlation coefficient (r) and by Bland and Altman analysis (by calculating mean bias and limits of agreement) to assess agreement between TTE and EC. *P* value  $<0.05$  was considered statistically significant.

## Results

Table 1 shows the basic clinical data of the patients. There was no significant difference between TTE and EC as regard preoperative and postoperative HR, SV, SVI, CO, and CI [Tables 2 and 3].

There was a strong positive correlation between TTE and EC as regard preoperative and postoperative HR, SV, SVI, CO, and CI [Tables 4 and 5]. Bland and Altman analysis showed low bias with accepted limits of agreement of HR, SV, SVI, CO, and CI [Tables 4 and 5].

CO showed a strong positive correlation with mean bias 0.01 and limits of agreement ( $-0.68$  to  $0.70$ ) at preoperative readings but with mean bias  $-0.01$  and limits of agreement ( $-1.21$  to  $1.18$ ) at postoperative readings [Figures 1 and 2].

Postoperative readings showed a significant increase in HR and a significant decrease in SV and CO (either by

**Table 1: Basic clinical data of the patients**

Age (year)	45.55 $\pm$ 7.93
Sex (Male)	43 (71.67%)
Weight (kg)	80.95 $\pm$ 12.11
Height (cm)	170.45 $\pm$ 6.64
Pneumonectomy/Lobectomy	36 (60%)/24 (40%)

**Table 2: Preoperative hemodynamic parameters determined by TTE and EC**

	TTE	EC	<i>P</i>
HR (b/min)	76.68 $\pm$ 12.77	76.78 $\pm$ 12.66	0.966
SV (ml)	79.55 $\pm$ 11.24	79.15 $\pm$ 10.87	0.845
SVI (ml/m <sup>2</sup> )	40.98 $\pm$ 6.45	40.83 $\pm$ 6.47	0.904
CO (l/min)	6.07 $\pm$ 1.19	6.06 $\pm$ 1.2	0.952
CI (l/min*m <sup>2</sup> )	3.14 $\pm$ 0.69	3.13 $\pm$ 0.71	0.977

**Table 3: Postoperative hemodynamic parameters determined by TTE and EC**

	TTE	EC	<i>P</i>
HR (b/min)	89.70 $\pm$ 12.95	89.72 $\pm$ 12.93	0.994
SV (mL)	62.07 $\pm$ 10.14	62.13 $\pm$ 12.52	0.975
SVI (mL/m <sup>2</sup> )	5.54 $\pm$ 1.06	5.55 $\pm$ 1.27	0.904
CO (L/min)	31.96 $\pm$ 5.56	31.93 $\pm$ 6.41	0.98
CI (L/min*m <sup>2</sup> )	2.86 $\pm$ 0.6	2.86 $\pm$ 0.68	0.998

**Table 4: Bland and Altman analysis and correlation of preoperative hemodynamic parameters determined by TTE and EC**

	Bland and Altman analysis			Correlation		
	Mean Bias	Lower LOA*	Upper LOA*	r	P	95% CI
HR (b/min)	-0.11	-1.25	1.02	0.999	<0.001	0.9983-0.9994
SV (mL)	0.37	-8.61	9.35	0.915	<0.001	0.8604-0.9483
SVI (mL/m <sup>2</sup> )	0.15	-4.54	4.85	0.931	<0.001	0.8866-0.9583
CO (L/min)	0.01	-0.68	0.70	0.957	<0.001	0.928-0.974
CI (L/min*m <sup>2</sup> )	0.003	-0.356	0.363	0.966	<0.001	0.9432-0.9795

\* LOA: limit of agreement

**Table 5: Bland and Altman analysis and correlation of postoperative hemodynamic parameters determined by TTE and EC**

	Bland and Altman analysis			Correlation		
	Mean Bias	Lower LOA*	Upper LOA*	r	P	95% CI
HR (b/min)	-0.02	-0.69	0.65	0.9997	<0.001	0.9994-0.9998
SV (mL)	-0.07	-13.17	13.04	0.846	<0.001	0.7547-0.9057
SVI (mL/m <sup>2</sup> )	0.03	-6.81	6.87	0.839	<0.001	0.7435-0.901
CO (L/min)	-0.01	-1.21	1.18	0.879	<0.001	0.806-0.927
CI (L/min*m <sup>2</sup> )	0.0002	-0.6282	0.6277	0.882	<0.001	0.8091-0.928

\* LOA: limit of agreement

**Table 6: Comparison of preoperative and postoperative hemodynamic parameters determined by TTE and EC**

	Preoperative	Postoperative	P
HR (b/min) by TTE	76.68±12.77	89.70±12.95	< 0.001
HR (b/min) by EC	76.78±12.66	89.72±12.93	< 0.001
SV (ml) by TTE	79.55±11.24	62.07±10.14	< 0.001
SV (ml) by EC	79.15±10.87	62.13±12.52	< 0.001
CO (L/min) by TTE	6.07±1.19	62.07±10.14	< 0.001
CO (L/min) by EC	6.06±1.2	31.93±6.41	< 0.001
SBP (mm Hg)	125±7.2	116.3±6.8	< 0.001
DBP (mm Hg)	83.7±6.4	71.3±4.9	< 0.001

TTE or EC), SBP and DBP as compared to preoperative reading [Table 6].

## Discussion

Thermodilution has been used as the “gold standard” for CO measurements in most studies. However, this requires patients to undergo cardiac catheterization. The use of TTE, as a standard reference, allows comparison of two non-invasive methods of measuring CO. Many studies have validated TTD as a reliable technique for CO monitoring.<sup>[1,2]</sup> TTE, as a reference, has a precision of about 30% and 10% bias compared to pulmonary artery catheter (PAC).<sup>[9]</sup> In addition, Malik *et al.* in 2014 concluded that the agreement between EC and PAC is clinically acceptable, and they can be used interchangeably.<sup>[10]</sup>

The development of a technology for continuous monitoring of SV and CO that is noninvasive, safe, reliable, and easy to use would be a monumental advancement for research and clinical use.

The EC shows accuracy and precision in studies of healthy volunteers. However, the reliability of perioperative use is not proven especially with skin incision, which may be a source of error in bioimpedance measurements.<sup>[11]</sup>

The present study demonstrated a good correlation of SV and CO values between EC and TTE before and after lung surgery, but EC is easier to use and operator-independent.

Our data show that EC has an excellent accuracy bias and limits of agreement in CO using TTE as the reference device (by Bland and Altman analysis).

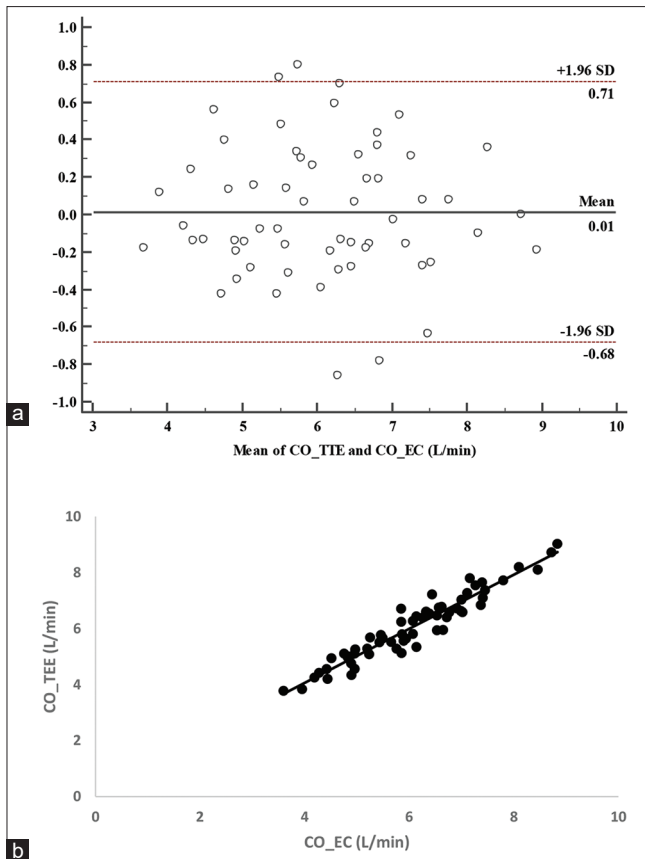
Several studies have compared EC with various tools as a reference. Some of these studies support the results of our study. However, we found no previous study assessing the agreement between EC and TTE with similar value limits before and after lung surgeries.

A comparative study of the use of Doppler-trans-esophageal echocardiography (TEE) and EC to TTE as the reference for measuring SV and CO in pediatric post-cardiac surgery patients who were hemodynamically stable and still on ventilator showed a good correlation between EC and TTE.

The authors argue that Doppler-TEE and EC are better tools for monitoring cardiac function trends than for determining absolute values.<sup>[12]</sup>

A study in 2012,<sup>[13]</sup> using EC as compared to TTE in obese pediatrics, showed that EC is reliable and accurate in measuring CO.

However, these results were in contrary to Tomaske *et al.*<sup>[14]</sup> who found unacceptable limits of agreement between EV and thermodilution, with a 48.9% error. Although the



**Figure 1: Preoperative correlation (a) and Bland and Altman analysis (b) of EC as compared to TTE**

bias for CO values between the Aesculon monitor and subxyphoidal Doppler flow measurements in the study was 0.31 L/min, CO values obtained by Aesculon monitor and subxyphoidal Doppler flow differed significantly.

As regard the hemodynamic changes after the surgery, postoperative readings showed a significant increase in HR and a significant decrease in SV and CO (either by TTE or EC), SBP and DBP as compared to preoperative reading in our study.

These results were in agreement with Wang *et al.*<sup>[15]</sup> who studied 30 patients underwent lung resections, and speckle tracking echocardiography was performed. EF significantly decreased after resection but stayed within the normal range >55% with significant increase in HR.

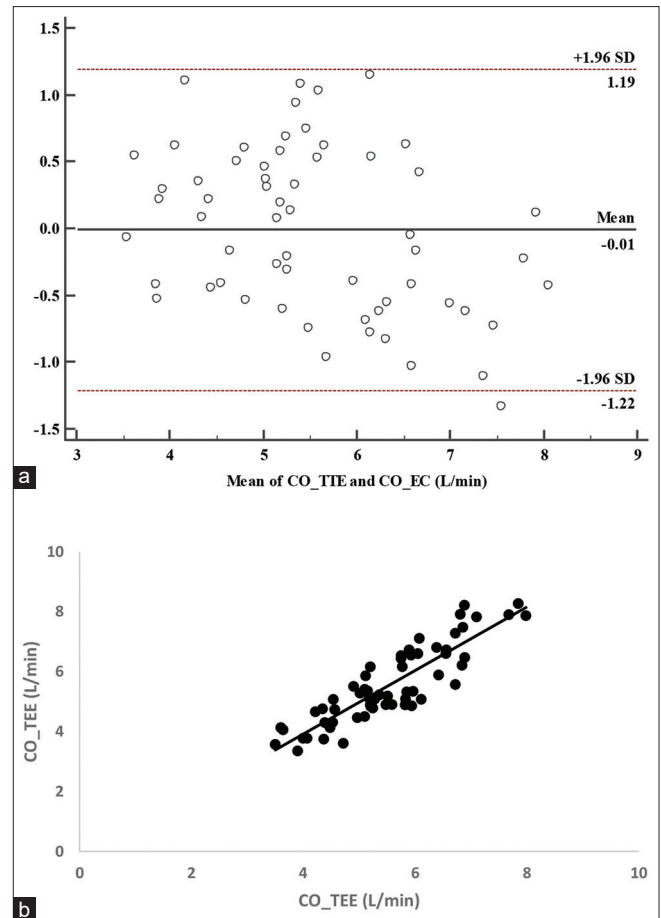
Further studies are needed to validate EC in other surgeries and in critical ill patients in different scenarios.

### Conclusion

Compared to the TTE, EC provides accurate and reliable CO, SV, and HR measurements before and even after lung surgeries.

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Nil.



**Figure 2: Postoperative correlation (a) and Bland and Altman analysis (b) of EC as compared to TTE**

### Conflicts of interest

There are no conflicts of interest.

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