Research Article

The Role of Electrical Cardiometry in Paediatrics and Neonatal Anaesthesia and Intensive Care: A Narrative Review

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Abstract

Invasive hemodynamic monitoring could be challenging among pediatrics, particularly infants and new-borns. This current narrative review aims to discuss and present the published literature that addresses the optimal use and validity of the electrical cardiometry (EC) device among pediatrics. This is a non-invasive continuous cardiac output and hemodynamic monitor that measures the electrical transthoracic bioimpedance. Literature search focused on PubMed (MEDLINE), Saudi Digital library (SDL), and Google Scholar database between 2010 and 2022. English language studies were included only. The retrieved data were peer-reviewed manuscripts, including print publications and case presentations. This review provided evidence that EC monitoring among the pediatrics age group was able to track CO changes over the time (Trend). However, EC absolute values for CO were interchangeable with the CO measurements derived from the thermodilution technique in some studies and were not interchangeable in some others. The variation in clinical conditions and surgical procedures affected the performance EC CO. In specific clinical scenarios, EC CO trend changes proved to be of extreme help during transportations and in operating rooms during PDA ligation. The EC technology is easy to use and is an addition for future developments in monitoring, particularly for the pediatric age group. More studies are recommended to improve further the precision of the absolute CO measurements and to study the impact of the EC on short- and long-term clinical outcomes.

Keywords: Cardiac output; Impedance cardiography; Hemodynamic monitoring; Paediatrics; Electrical cardiometry

1. Introduction

In adults, the thermodilution technique (Fick Principle) is recognized as the gold standard technique for cardiac output (CO) measurements. However, unfortunately, this method is of limited use among pediatrics during acute clinical conditions due to its invasiveness and associated risk of morbidity [1]. Current practice adopted by several physicians is to measure the CO in neonatal units with bedside echocardiography (Echo). However, the Echo examination is not suitable for continuous monitoring and requires training. This indicates the need for other alternatives to continuously monitor the CO in this age group [2,3]. Electrical Cardiometry (EC) is a non-invasive method designed for continuous cardiac output (CO) measurement and fluid intake guidance.

The EC determines an estimate of the stroke volume (SV) by measuring the thoracic electrical bio impedance (TEB) with relation to the cardiac cycle. The method of EC is based on the fact that the conductivity of the blood in the aorta changes during the cardiac cycle. The orientation of red blood cells (erythrocytes) in the aorta prior and shortly after aortic valve opening affect the conductivity and hence the TEB. Prior to opening of aortic valve, the red blood cells (RBCs) assume a random orientation and hence an electrical current passing through the aorta will face low conductivity as a result of this random position of the RBCs. Very shortly after aortic valve opening, the pulsatile blood flow forces the red blood cells to align in parallel with the blood flow. Now the same electrical current passes the red blood cells more straight forward with a higher conductivity. The alignment of RBCs in the aorta contributes to the significant change in the impedance soon after aortic valve opening (Figures 1,2). EC relies on the change in impedance of the aortic blood to calculate the CO and other hemodynamic parameters. EC estimates stroke volume (SV) and CO based on body mass and peak aortic acceleration of blood flow, and a measurement of flow time [4,5]. EC was evaluated by several researchers among children and neonates as a continuous CO monitor [6,7]. EC is portable, and this offers a considerable advantage over invasive monitors, particularly during transfer [2,8]. This current narrative review aims to search for published literatures that address the optimal use and validity of EC as a non-invasive continuous cardiac output among pediatric age groups. The limitations, lessons learned, and areas for future research and improvements will be discussed.

Figure 1: EC electrode array for measuring Thoracic Electric Bio impedance (TEB)

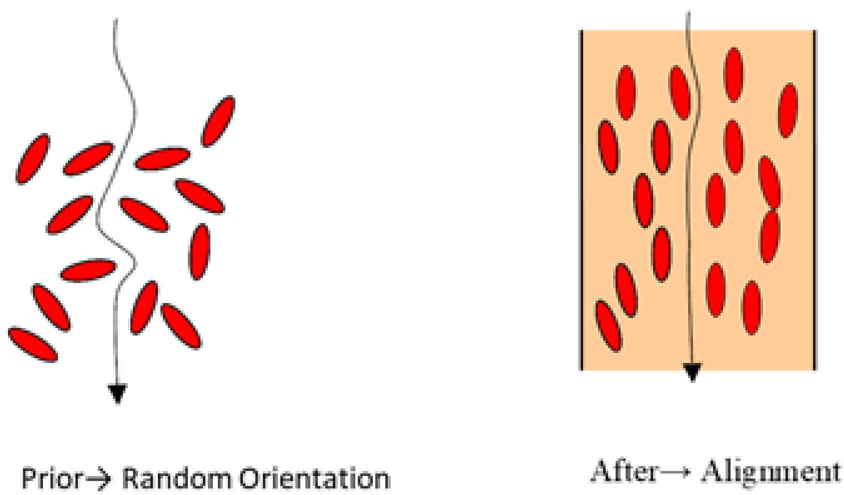

Figure 2: Orientation of red blood cells (RBCs) in aora prior and after aortic valve opening.

2. Methods

This narrative review was conducted following approval by the local research and ethics committee of King Fahad Hospital (IRB KFHH No. (H-05-HS-065), Ministry of Health, Hofuf City, Saudi Arabia. Research proposal approval number is RCA NO: 02-E-2022.

2.1 Literature Search

Relevant abstracts and published studies were retrieved from the database in specific PubMed (MEDLINE), Saudi Digital library (SDL), and Google Scholar between July 2010 and January 2021. Keywords included: cardiac output, electrical cardiometry, bioimpedance, pediatric, hemodynamic monitoring, anesthesia, critical care, and surgery. There is no restriction on a specific study design. Observational studies, randomized controlled trials, pilot, retrospective studies, case reports were included. English language studies confined to humans were only included. The studies reference list was searched for additional papers.

2.2 Population Selection

Pediatrics monitored by electrical cardiometry (EC, ICON, Cardiotronic, Osypka Medical, Inc., La Jolla CA, USA) in intensive care units (ICU), operating theatres, and during transportation. Patients with respiratory support were included and those > 18 years excluded.

2.3 Data extraction

The following data will be extracted: the name of the first author, publication year, type of study, sample size, type of surgery, and type of invasive or non-invasive devices. The effect of cardiac output (CO) and stroke volume variation (SVV) parameters of EC on hemodynamic monitoring and guided fluid therapy were identified for discussion.

3. Results

Results of this search provided evidence that EC was able to track CO values with time and to follow the trend changes in CO. However, more studies are still required to improve the precision of the EC absolute CO values compared to gold standard methods. The review looked into different studies comparing the EC with other CO monitors and covering different practical applications of the device, as studied by various research groups among pediatrics. The results and conclusions vary widely because of the heterogeneity of these published studies. The comparisons of the EC with different devices at different clinical and surgical conditions could be responsible for these variations in percentage errors and accuracy of the EC absolute CO values between various studies. However, there is growing evidence to support the benefits of EC as a non-invasive continuous cardiac output trend monitor among pediatrics, particularly in intensive care units, operating theatres, and during transportation. EC was able to guide intravenous fluids administration without the need for an invasive approach. More studies are still needed with EC at various clinical conditions to improve the accuracy of the absolute CO measurements.

4. Discussion

Cote et al. in 2015 provided evidence that supports the EC role as a continuous noninvasive CO device that can monitor rapid trend changes among pediatrics. They build their suggestion from the analysis of 402 pediatrics patients' anesthesia records [9] Norozi et al. [5] and Narula et al. [6] studies also presented acceptable agreements between the CO of EC and that derived by the Fick principle (Gold standard) among pediatrics suffering from various tructural heart diseases. Mansfield et al. in a recent systematic review and meta-analysis also reported no significant difference between the CO derived by EC and that by other devices (except in neonatal stroke volume studies) [10]. However, Mansfield and his colleagues blamed the wide range in the percentage error they noted in their analysis on the heterogeneity of the study designs included and the difference in technology.

EC CO accuracy

Various studies looked into the accuracy of the absolute EC CO and reported conflicting results. Sanders et al., in a recent meta-analysis (2020), reported a wide range of bias with EC CO, although their pooled bias was close to zero [11]. One of the limitations in their meta-analysis was including both adults and pediatrics together in the analysis. In 2015, Suehiro et al. performed a systematic review and meta-analysis that focused on the pediatric population and looked into the precision of several minimally-invasive CO devices, including EC [12]. Their inter-study heterogeneity was significant because of the inclusion of different devices. However EC CO had the slightest bias and the lowest percentage of error. The variation in clinical conditions and surgical procedures significantly affected the CO monitors' performance included in Suehiro et al. meta-analysis. Cardiac surgery had the lowest bias and mean percentage error (MPE). Three years later (2018), Altamirano-Diaz et al. demonstrated that the CO measurements by EC in pediatric patients undergoing coarctation of aorta repair were equivalent to those by the transoesophageal echocardiography (TEE) provided that no increase in left ventricular output (LVO) is present. The increase in LVO impacts the accuracy of TEE CO and hence its agreement with the EC CO [2]. In another study group among pediatrics suffering from sepsis and septic shock, the evaluation of CO by arterial waveform analysis yielded the worst findings. The bias was negatively influenced by the low systemic vascular resistance (SVR) associated with sepsis. This was not the case with EC. EC provided real-time guidance and improved outcomes, as stated by Rao et al. in their observational pilot study [13]. The exact clinical circumstance should be defined during the validation of any device. EC performance could be suitable for certain clinical conditions, as in sepsis, while unsuitable for others [14,15]. A study by Torigoe et al. [16] in 2015 among low birth weight preterm infants with patent ductus arteriosus (PDA) provided evidence that EC was interchangeable with echocardiography (Echo) during mechanical ventilation. Boet et al. [17] in 2016 also noted that the CO of EC was in good correlation with Echo CO in hemodynamically stable preterm infants. However an overestimation was noted at high CO values. In 2017, Hsu et al. [18] reported a similar finding among preterm infants with PDA. They noted that the negative bias and the error percentage were more prominent with high CO values (>280 ml/kg/min). High-frequency ventilation (HFV) was also found to affect the EC CO. In a prospective observational study by Song et al. (40 preterm neonates), a decline in the agreement between EC CO and Echo CO was observed with HFV [19]. This could be attributable to several factors, one of them is the effect of chest wall vibrations on CO readings that associated HFV, and another is the similarity between the frequency utilized by EC and that by the high-frequency ventilator (12 Hz). Another possibility is that the increase in intrathoracic pressure caused by HFV can increase the distance from the electrodes to the descending aorta and hence diminish the bioimpedance signals. Results from Noori et al. study indicate that smaller and sicker infants have more reliable CO readings, as they tend to move less, and hence the artifacts are reduced [20].

For obese children, Simone et al. found no evidence of a male-to-female contribution to CO levels. The only statistical significance was in the preschool age but not in school-aged children. It is essential to normalize the CO to the ideal BSA for each age [21]. Boet et al [17] results indicate that SV and CO increase with higher birth weight and gestational age, and Grollmuss et al. [22] found a significant linear correlation between SV and birth weight.

Lotfy et al. conducted a randomized controlled trial among 42 infants undergoing surgical hepatoportoenterostomy (Kassi procedure). The EC CO was persistently higher than that measured by trans esophageal Doppler (TED CO) despite excellent reliability [23]. This reliability was the same within the Grollmuss et al. study, where the SV of EC and Doppler-TTE were also found to be interchangeable among newborns following cardiac switch surgery [22].

EC role in specific medical situations

The accuracy of EC as a monitor for CO varies from one clinical scenario to another. The pro and cons, and limitations will be discussed in the following specific clinical applications.

During emergency transportation

Boet et al. prospective cohort study noted that SV and CO trend monitoring was possible with EC without interference during neonatal transportation and with reliability compared to heart ultrasound [24]. This is an advantage as it allows for the continuous monitoring during the transfer of critically ill pediatric patient to specialized centres. However, it is essential to take into consideration the tendency for the SV and CO of EC to be higher than other devices as reported by Boet et al. [23] versus (vs.) ultrasound, Grollmuss et al. vs. Doppler-TTE [22] and Lotfy et al. vs.TED [23].

During patent ductus arteriosus ligation (PDA)

Lien et al. succeeded in monitoring with EC the significant reduction in SV (>73%) and the increase in SVR immediately following PDA ligation. It was the decrease in SV rather than the increase in HR that contributed to the deterioration in CO. The study was performed among very low birth weight (≤1500 g) infants [25]. The SVR increase after ligation was significant with infants suffering from larger PDAs. The smaller the infant, the greater the likelihood of cardiovascular impact. EC also noted the return of the CO to 92 and 94% of baseline respectively within 24 and 48 h. Hsu KH et al. study had proved that Infants with PDA had higher baseline CO by EC compared to those without PDA [26]. Hsu KH et al. also demonstrated that EC and Echo have a wide but clinically acceptable agreement in measuring CO in preterm infants with hemodynamically significant PDA [18]. The utilization of non-invasive cardiac output monitors duet al ring PDA ligation was also highlighted by several research teams but with different monitors. Noori et al. [27] and McNamara et al. [28] with serial echocardiographic analysis, presented similar results to that by EC in Lien et al. study. Another study with pulsed doppler technique by Linder et al. [29] demonstrated a decrease in the SV among preterm infants with very low birth weight in two days following PDA ligation. Rowland et al. also noted by echocardiography that the newborn myocardial performance was sensitive to afterload due to the immaturity of their hearts [30].

During cardiac arrhythmias and depression

Infants are less able to augment their cardiac output by increasing stroke volume as a result of their low myocardium compared to adults [31]. To maintain cardiac output, infants are classically described as heart rate dependent and can have a higher cardiac output in relation to their BSA than adults. Green et al. demonstrated that sevoflurane administration to healthy infants could lead to a nodal rhythm [32]. Dewhirst et al. also showed that following anesthesia induction, tachycardia developed in 50% of the pediatric patients in their study despite no significant changes in blood pressure [33]. Vanderhoek et al. reported that a 6-year-old boy developed supraventricular tachycardia (SVT) during an upper endoscopy while under general anesthesia [34]. EC was applied in this case to measure the effect of SVT on cardiac index and SV before and after adenosine administration. Following administration of adenosine, the CI fell by 41%, while SV decreased by 9%. This highlights the relationship between CO and HR in children and the possible future role of EC in arrhythmia monitoring and guided management. HR rhythmic changes and their effects on CO among infants can be easily monitored by EC. In another specific and rare clinical condition named Pompe disease. Liu et al. were capable of detecting the hemodynamic trend changes that associated this disease more reliably with EC than with pulse contour analysis [35]. In this rare case, an enzyme replacement therapy is usually used to reduce the severe organ dysfunction that associates with the disease. EC CO monitoring proved to be of importance in detecting the moderate cardiac depression associated with anesthesia induction.

Hemodynamics' normal range for Neonates

Hsu et al study was one of the first studies from the Asia Pacific region to create reference normal range for neonates and premature of different age groups and weight [5].

EC Limitations

In Kadafi et al. recent study (2021), EC was unable to assess fluid responsiveness and preload adequately. They studied the EC SVV cut-off values compared to the ultrasonic CO monitor in shock children on mechanical ventilation [36,37]. Unfortunately, the sensitivity and specificity of EC were only 58% and 74%, respectively, while the optimal cut-off point of SVV was 16.5%. In 2016 Hsu et al. suggested that the hemodynamic reference ranges of EC can only be of help as an alarm, when CO falls outside the reference value for neonates in NICU [5]. Hsu et al. added that the hemodynamic reference of EC is affected by the neonates' maturity, age, and body size. The weight and BSA had a positive correlation with CO, while the HR and SVR had a negative correlation with CO. SVV is also affected by the diameter of the blood vessels. The larger the neonate, the less the SVV and the more is the CO. Hence the cardiac index is better as it includes the BSA. CI is recommended for cardiac performance assessment among neonates to reduce maturity differences.

5. Conclusion

This review provided evidence that EC can track CO changes with time and warn against significant hemodynamic changes, but more in the future are still required to improve the precision of the absolute EC CO measurements as presented in several studies. The variation in clinical conditions and the type of the surgical procedure affected the performance of the EC CO. In specific clinical scenarios, the EC CO was found to be of extreme help as during transportations of neonates and infants, in operating rooms during PDA ligation, and in NICU.

Potential conflict of interest

Yasser Nassef is a memeber of the advisory board for Osypka medical GmbH.

All other authors reported no potential conflict of interest relevant to this article.

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IRB number

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Clinical trial registration number

Not applicable.

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