Consistency between Impedance Technique and Echocardiogram Hemodynamic Measurements in Neonates

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Abstract

Objective The aim of this study was to validate impedance technique (IT) by investigating the agreement in cardiac output measurements performed by IT and echocardiography (ECHO).

Study design This is a prospective observational study, including a total of 30 neonates who underwent hemodynamic measurements by IT and ECHO. To determine the agreement between both methods, we performed IT to measure stroke volume (SV-IT) and cardiac output (CO-IT) immediately before or after ECHO to measure SV (SV-ECHO) and CO (CO-ECHO). The precision and accuracy of the IT relative to ECHO were assessed.

Results SV-ECHO and SV-IT were (4.45 ± 0.78) and (4.54 ± 0.81) mL, respectively. The bias and limits of agreement of SV-IT were 0.09 mL and (−1.92 to 1.73) mL, respectively. The true precision of SV-IT was 27.3%. Furthermore, CO-ECHO and CO-IT were (0.62 ± 0.12) and (0.61 ± 0.12) L/min, respectively. The bias and LoA of CO-IT were 0.01L/min and (−0.33 to 0.31) L/min, respectively. The true precision of CO-IT was 28.3%.

Conclusion Agreement between the IT and ECHO in the cardiac output measurement appeared acceptable. However, the accuracy and precision of the IT approach should be further investigated using a larger sample.

Keywords

- impedance technique
- echocardiogram
- cardiac output
- Bland–Altman analysis

Cardiac output monitoring is commonly applied in neonatal intensive care, especially for investigating circulatory management of neonatal sepsis, septic shock, and congenital heart disease.[1] Over the recent years, measurements of cardiac output by impedance technique (IT) have been increasingly utilized for hemodynamic monitoring in adults; nevertheless, this approach has been rarely applied in neonates. Whether the IT can be used to accurately measure the cardiac output in neonates needs to be further investigated.[2] In this study, IT was compared with echocardiography (ECHO) for cardiac output measurement.

Materials and Methods

Subjects

This was a prospective observational study. A total of 30 clinically stable patients were enrolled from the Dongguan Children's Hospital Neonatal Intensive Care Unit (NICU) between May 2018 and June 2018. Exclusion criteria were the following: congenital heart disease diagnosed by ECHO and prenatal clear congenital developmental abnormalities. The study was approved by the institutional review board of the hospital. Informed consent was obtained for all subjects

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before enrollment. The infants' birth weight, gestational age, mode of delivery age respiratory support heart rate (HR) and respiratory rate (RR) were noted. Hemodynamic measurements using ECHO and IT device were not performed simultaneously in our study; therefore, HR and RR were recorded separately during each period.

Research Methods

Hemodynamic measurements in the study were made using the noninvasive cardiac system (NICaS, NI Medical, Israel) and Doppler (Philips CX50, Philips). We performed IT to measure stroke volume (SV-IT) and cardiac output (CO-IT) immediately before or after ECHO to measure SV (SV-ECHO) and CO (CO-ECHO). The interval between the two methods did not exceed 10 minutes. All inspections were performed in a quiet state. Each measurement was taken three times and the average value was calculated. All ECHO measurements were performed by a single echocardiographer, who was blinded to the IT measurements.

For NICaS, patients were placed in a supine position, and the electrode pieces were pasted on the obvious part of the wrist and ankle joint (►Fig. 1). The relevant parameters were then imputed in the system interface. NICaS uses bioimpedance technology and has been well demonstrated to be associated with pulmonary artery catheter thermodilution.[3] It is US FDA approved.[4] SV is measured by applying an alternating electrical resistance by using sensors placed on the wrist of the hand and the contralateral ankle, and calculated by proprietary algorithm.[3] Each hemodynamic measurement took by NICaS was an average of 60 seconds. During the 60 second-period, HR is measured constantly by an electrocardiograph (ECG) channel connected to NICaS. CO is calculated by $CO = HR \times SV$.

ECHO was performed as previously described[5]: the CX50 Doppler was applied using a probe frequency of 3.5 MHz. The patient was laid down on the left side. Each hemodynamic measurement took by Doppler was over three to five cardiac cycles. If the Doppler tracing was similar in shape and size, a still frame was acquired. SV was calculated using the velocity time integral (VTI) and aortic diameter (D). The formula $(\pi) \times (D/2)^2 \times VTI$ is used to calculate the SV by the built-in software. SV is multiplied by the HR to derive CO.

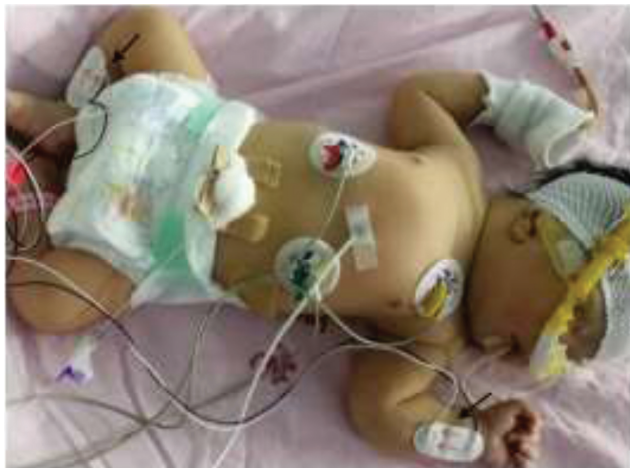

Fig. 1 Schematic diagram of noninvasive cardiac system, showing the two impedance electrodes are applied to the left wrist and to the right ankle (arrows).

Statistical Analysis

Statistical analysis was performed using SPSS-13 software (SPSS, Inc., Chicago, IL). Bland-Altman plots were drawn using MedCalc, version 15.0 (MedCalc Software, Ostend, Belgium). Continuous variables were expressed as mean ± standard deviation (FO1 ± SD) and categorical variables were displayed as the number of subjects and its percentage. Paired *t*-test was performed to compare the differences between the two datasets. The consistency was compared using the Bland–Altman analysis, and limits of agreement (LoA, FO1 ± 1.96 SD) were analyzed by calculating the differences between the two measurement methods. NICaS was calculated using the precision method (1.96 SD/average of the two methods) × 100%[6]; the calculation formula for correcting the precision of IT is FO2.[7] According to previous studies, the ECHO precision is 30% [8] and correction precision <30% is considered good.[9] A *p*-value <0.05 was considered to be statistically significant.

Results

Among the 30 infants included in the study, there were 17 males and 13 females, with gestational ages ranging from $34^{0/7}$ to $40^{5/7}$ weeks. The birthweights of the infants ranged from 2,000 to 3,680 g. Twenty-three infants were delivered vaginally and seven by cesarean section. Most of the infants were spontaneously breathing (►Table 1). There was no significant difference between the HR ($p = 0.191$) in ECHO and NICaS detected period. There was also no significant difference between the RR ($p = 0.506$) in ECHO and NICaS detected period (►Table 1).

The stroke volume (SV) measured by ECHO (SV- ECHO) and IT(SV-IT) was (4.45 ± 0.78) and (4.54 ± 0.81) mL, respectively (►Fig. 2). The bias and limits of LoA of SV-IT were 0.09 and (−1.92 to 1.73) mL, respectively. The true precision of SV-IT was 27.3%. CO measured by ECHO (CO-ECHO) and by IT (CO-IT) were (0.62 ± 0.12) and (0.61 ± 0.12) L/min, respectively. The bias and LoA of CO-IT were 0.01 and (−0.33 to 0.31) L/min, respectively. The true precision of CO-IT was 28.3% (►Fig. 2).

Discussion

Cardiac output monitoring is an important approach for measuring the hemodynamic status of patients.[1] This method can be divided into two categories: invasive and noninvasive method.[10,11] Invasive approach is represented by pulmonary artery flotation; however, the method becomes very challenging when applied to neonates due to volume overload and low temperature caused by repeated and long-term measurement.[12] The measurement of neonatal cardiac output mainly relies on noninvasive methods, that is, ECHO.[13] However, patients in shock require continuous monitoring of cardiac output, which cannot be performed by ECHO.

Table 1 The general characteristics of cases

Character	All cases ($n = 30$)
Birth weight (g)	2,913.3 ± 423.1
<1,500, *n* (%)	0/30 (0)
1,500–2,500, *n* (%)	5/30 (16.7)
>2,500, *n* (%)	25/30 (83.3)
Sex, *n* (%)	
Male	17/30 (56.7)
Female	13/30 (43.3)
Gestational age (wk)	37.5 ± 1.9
<37	11/30 (36.7)
≥37	19/30 (63.3)
Mode of delivery, *n* (%)	
Vaginal	23/30 (76.7)
Cesarean section	7/30 (23.3)
Age (d)	3.2 ± 1.8
Respiratory support, *n* (%)	
None	21/30 (70.0)
NCPAP/HFNC	9/30 (30.0)
HR-ECHO, beat/min	135.9 ± 13.1
HR-IT, beat/min	137.1 ± 12.7
RR-ECHO, beat/min	47.1 ± 5.1
RR-IT, beat/min	47.3 ± 5.4

Abbreviations: CO, cardiac output; ECHO, echocardiography; HFNC, high-flow nasal cannula HR, heart rate; HR-ECHO, heart rate recorded during ECHO measurement period; HR-IT, heart rate recorded during IT measurement period; IT, impedance technique; NCPAP, nasal continuous positive airway pressure; RR, respiratory rate; RR-ECHO, respiratory rate recorded during ECHO measurement period; RR-IT, respiratory rate recorded during IT measurement period.

IT is a noninvasive and continuous method of cardiac output measurement. Yet, the accuracy and precision of the IT cardiac output measurement in neonates still remain controversial. Weisz et al[14] have compared the consistency of IT and ECHO in 97 neonates and found significant deviations (up to 30%) between the two methods. Furthermore, Noori et al[5] and Shahab and colleagues have performed a total of 115 measurements in 20 neonates, finding that the difference between IT and ECHO measurement CO was 4 mL/min; in addition, the correction precision was <30%. Moreover, the author believed that the accuracy and precision of IT were equal to that of ECHO measurement. These data are consistent with our findings, suggesting that the CO value measured by NIcaS using the IT principle is equivalent to that of ECHO.

ECHO is a noninvasive detection method. The precision of ECHO compared with thermal dilution method and Fick method is approximately 30%,[12] which is within acceptable range. Since the gold standard was not used for comparison in this study, it was necessary to correct the accuracy and precision.[5] After correction, the precision was 27.30%, of which less than 30% is acceptable. In addition, IT is more accurate when measuring cardiac output in adults compared with neonates.[15] IT used for adults relies on analyzing the change of body resistance of each heart beat; the final cardiac output data obtained by SV are then calculated. Some studies suggest that there may be differences in body surface area, weight, and circulatory system pathway between neonates and adults; thus, the current formula needs to be corrected to further improve the precision of impedance measurement for neonatal cardiac output.[5,15,16]

The study has several limitations. First, we evaluated the validity of cardiacoutput using ECHO, which is not the gold standard. At present, the gold standard is believed to be thermodilution.[3] However, this invasive method has high risk to be used in newborn populations. It has its own significant limitations to estimate cardiac output. Second, hemodynamic measurements using different methods were not underwent simultaneously in our study; therefore, hemodynamic changes may happen between the measurements. However, both measurements were taken sequentially in a quiet state, equality of HR, and RR was record. Third, the sample size

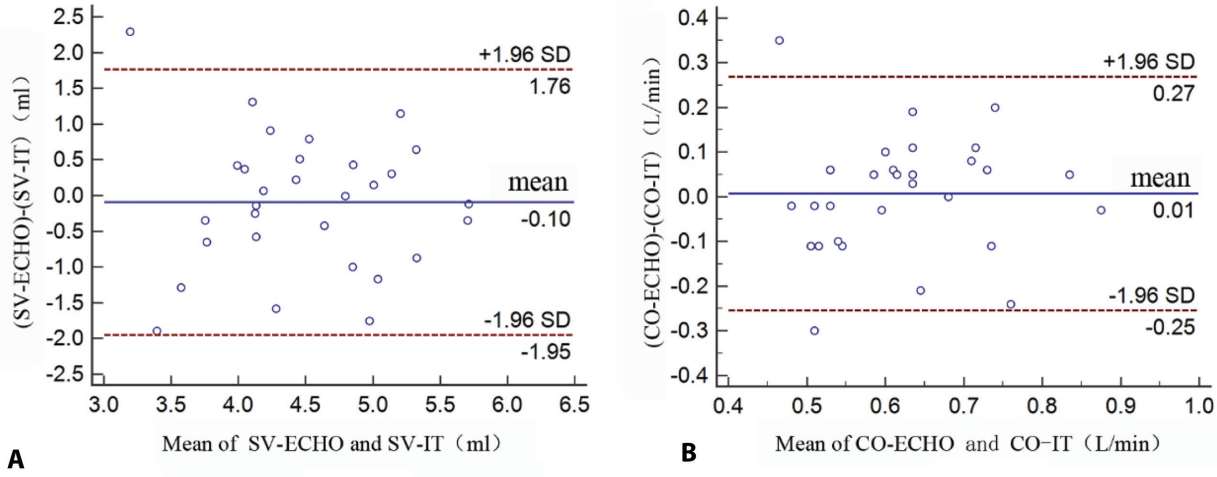

Fig. 2 Bland–Altman plot depicting the agreement expressed in milliliter between the SV estimated by ECHO and IT (**A**). Bland–Altman plot depicting the agreement expressed in liter per minute between the CO estimated by ECHO and IT (**B**). CO, cardiac output; ECHO, echocardiography; IT, impedance technique.

of 30 patients is small. Large clinical trials are needed to confirm our fndings.

In conclusion, agreement between the IT and ECHO in the hemodynamic measurement is acceptable, and the IT may be performed as an alternative to ECHO cardiac output measurements in neonates.

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Conflict of Interest

None declared.

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