ORIGINAL ARTICLE

Agreement of cardiac index measurements between ultrasonic cardiac output monitor and transthoracic echocardiography in neonates

Concordance entre ultrasonic cardiac output monitor et échocardiographie transthoracique pour la mesure de l'index cardiaque chez le nouveau-né

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Abstract

Objectives: To evaluate the agreement of cardiac index (CI) calculated by Ultrasonic sonic cardiac output monitor (USCOM) and transthoracic thoracic echocardiography (TTE) in order to know if we can recommend USCOM in our pediatric intensive care unit (PICU).
Design: Prospective observational evaluative study carried out over a period of 3 months
Setting: PICU at children's hospital in Tunis
Participants: All newborns without tracheostomy or a known congenital heart disease, admitted to the PICU during the study period were enrolled.
Interventions: Paired and consecutive measurements of CI were obtained in all patients with both technologies. All measurements by TTE and USCOM were performed by two distinct operators. It is the average of three successive measures of the CI, in the same patient, with each technology, which was considered.
Agreement of CI between the 2 techniques was assessed by Bland-Altman analysis and percentage error.
Measurements and Main Results: Forty-two infants were analyzed with the mean (standard deviation) gestation 36 weeks (5 days), age 1 days (1.09) , and weight 2.9 kg (0.87). Respiratory failure was the main cause of admission 75%. At the time of the study, 33 (75.%) patients were ventilated artificially. Bias (mean difference) of the CI between the two methods was 1.2 l/min/m2 and precision (± 2 SD of differences) was 1.08 l/min/m2.
The MPE of CI measurement for USCOM vs TTE was 54.9%.
Conclusions: The USCOM showed a poor agreement to TTE measures of CI. The two methods cannot be considered interchangeable.

Key words: Cardiac output, newborn, echocardiography, monitoring, USCOM, noninvasive cardiac output monitoring

Résumé

Objectif: Evaluer la concordance de l'index cardiaque (IC) mesuré par Ultrasonic cardiac output monitor (USCOM) et par echocardiographie transthoracique (ETT) chez le nouveau-né
Design: Étude prospective observationnelle durant une période de 3 mois
Lieu: Service de réanimation pédiatrique polyvalente de l'hôpital d'enfants Béchir hamza de Tunis
Patients: Tous les nouveau-nés n'ayant pas de trachéotomie et non porteurs de cardiopathies congénitales et admis au service de réanimation pédiatrique durant la période d'étude ont été inclus dans l'étude.
Interventions: Des mesures appariées et consécutives de l'IC par USCOM et ETT ont été réalisées chez tous les patients par 2 opérateurs différents. Trois mesures consécutives chez tous les nouveau-nés ont été réalisées par chaque opérateur.
La concordance des mesures de l'IC entre USCOM et ETT a été évaluée par l'analyse de Bland-Altman et le calcul du pourcentage d'erreur
Résultats: Quarante-deux nouveau-nés ont été étudiés avec en moyenne (déviation standard) un âge gestationnel de 36 SA (5 jours), un âge chronologique de 1jour (1,09) , et un poids 2,9 kg (0,87). La détresse respiratoire (75%) était la principale cause d'admission. Au moment de l'étude , 33 (75.%) patients étaient ventilés artificiellement. Les mesures par USCOM surestimaient l'IC avec un biais de 1,2l/min/m2 avec une précision de 1.08 l/min/m2.
Le pourcentage d'erreur de l'USCOM vs ETT était 54.9%.
Conclusions: La concordance des mesures de l'IC par les 2 techniques est faible. Les 2 techniques ne peuvent pas être interchangeables

Mots clés: Cardiac output, nouveau-né, échocardiographie, surveillance, USCOM, surveillance non invasive du débit cardiaque

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Introduction

Hemodynamic assessment of critically ill newborns admits many challenges especially in developing countries due to the lack of equipment and skills.
The commonly used variables such as heart rate, non-invasive blood pressure, and diuresis are not well correlated with cardiac output (CO) (1). Lactate serum level and oxygen central venous saturation are global indicators of tissue oxygenation but remain insufficient to guide hemodynamic support. Although the invasive methods using the principle of thermodilution remain the gold standard of CO measurement (2-6) in adults, they are usually not applicable and not suitable for neonates even in developed countries where transthoracic echocardiography (TTE) represents the reference technique (7,8). Indeed, TTE has the disadvantages of being a time consuming technique, requiring sophiscated and expensive machines, and a skillful operator, conditions that are not always met in developing country.
Ultrasonic cardiac output monitor (USCOM) is a more accessible technology and has been available since 2001, using continuous wave Doppler to calculate CO. It is designed for rapid and non-invasive CO assessment, and requires no prior experience of echocardiography. It has been validated in a canine model (9) and in adult patients where it has been compared to CO pulmonary artery thermodilution technique (2-6,10-16). Few studies have so far compared CO assessed by USCOM and Doppler echocardiography (7,8,17-19) or pulmonary artery thermodilution (20-22) in children and newborns.
The aim of this study was to evaluate in neonates the correlation and agreement of cardiac index (CI) calculated by USCOM and TTE.

Methods

Design

This was a prospective observational evaluative study, carried out over a period of 3 months, from April 1st to June 30th, 2016, in the PICU at Béchir Hamza children's hospital in Tunis. This PICU includes 14 intensive care beds, and admits patients at different pediatric ages from the newborn until the age of 14 years. It receives about 650 admissions per year for the management of diseases most often medical, more rarely surgical, including postoperative cardiac surgery. The study was approved by children's hospital of Tunis committee and was considered to be of minimal risk to the patients.

Inclusion criteria

All newborns without a known congenital heart disease, admitted to the PICU during the study period were considered for enrollment in the study. Depending on the availability of the operators, a patient admitted to the PICU may be included on any day of his or her stay.
Newborns with a cardiac architectural anomaly or evidence of intra- or extra-cardiac shunting on cardiac ultrasound and/or patients in whom the USCOM pattern obtained did not meet the Fremantle quality criteria (23) were excluded.

Study protocol

Two operators A and B participated in the study. Operator A has 10 years' experience in echocardiography. Since the acquisition of the USCOM monitor, operator B has been trained, and has completed more than 30 CI measurements before the start of the study.
Correlation and concordance between USCOM and echocardiography were studied on paired and consecutive measurements of CI, obtained with both technologies. All measurements by echocardiography were performed by the operator A. The measurements by USCOM, were carried out immediately after the measurements by echocardiography, by the operator B. Operators were blind to the results obtained by each other. To overcome intra-observer variability, the average of three successive CI measurements was taken for each technology.

Measurements

All patients were examined in slightly head up position. The measurements were performed on a patient calm and well warmed. Intra-oral instillation of a few drops of 10% glucose serum was allowed to calm newborns who were not sedated.

Transthoracic echocardiography

The echocardiographic examination was carried out using the device SonoSite M-Turbo (Bothell, USA) and the P10x (8-4 MHz) probe. When the angle of insonation was less than 15° the measurement was validated. CO (l.min–1) was calculated as the product of velocity time integral (VTI), valve cross-sectional area(CSA) and heart rate (HR) (7,24). The CI (ml/min/m2) was obtained by reporting CO to body surface area.

Ultrasonic cardiac output monitor

The USCOM (USCOM Ltd., Sydney, Australia) was introduced for clinical use in 2001. It can measure and calculate more than 20 hemodynamic parameters such as CI, CO, stroke volume (SV) and evaluate the inotropism function of the cardiac muscle. USCOM measures the HR, VTI and calculate the CSA using the aortic outflow tract diameter (AOT) based on a validated nomogram derived from height and weight (13).
The USCOM measurements were performed with a 2,2 MHZ USCOM transducer. The transducer is placed in the suprasternal notch to obtain an optimal flow signal at the aortic valve. The device displays the Doppler curve, and the operator adjusts the angle of insonation to obtain a flow profile that is well defined at the base, peak and starting and stopping blood flow. All the measurements were taken with the flow trace (FT) mode where the outer countour of the Doppler profile of all complexes displayed was drawn. For each measurement, reported values are the average of all complexes on screen.

Statistical analysis

Descriptive analyses for continuous data were described

as mean ± SD. Pearson's correlation was used to assess the results for each method. Bland Altman (25) analysis was performed to compare the mean CI value obtained by USCOM and TTE (bias and limits of agreement) and percentage error was calculated as suggested by Critchley and Critchley (26). According to these authors, a mean percentage error (MPE) of less than or equal to 30% allows assert the relevance of the tested technique to the reference technique. The MPE is also used to compare to other studies.

The Intra Class Coefficient (ICC) was calculated for the set of three USCOM and TTE measurements to evaluate the intra-observer variability (27).

Results

During the study period, 44 newborns were enrolled. Two were excluded because of congenital heart disease revealed at TTE assessment in one patient and discomfort in the second during placement of the Doppler ultrasound probe at the supra- sternal notch . Forty-two infants were finally analysed, with a mean (standard deviation) gestation of 36 weeks (5 days), age of 1 day (1.09) and weight of 2.9 kg (0.87). Respiratory failure was the main cause of admission 75%. At the time of the study, 33 (75.%) patients were ventilated artificially (Table 1).

Table 1. Patient characteristics

	(n=42)
Gestational age weeks , mean (SD)	36 (5)
Days of age, mean (SD)	1(1,09)
Weight kg, mean (SD)	2.9 ± 0.87
Height cm, mean (SD)	46 ± 4.47
Skin surface cm^2, mean (SD)	0.18 ±0.03
Type of diagnosis:	
Neonatal respiratory distress	39
Bronchiolitis	1
Septic choc	1
Acute heart failure	1
Ventilatory support n(%)	
Invasif	35(83)
Non invasif	5(12)
No support	2(5)

Pearson correlation's coefficient between the two techniques was good for HR (r=0.48; p =0.001); AOT (r=0.7; p < 0.0001); VTI (r=0.52; p=0,0003) and CI (r=0.45; p =0.002) (Fig.1).

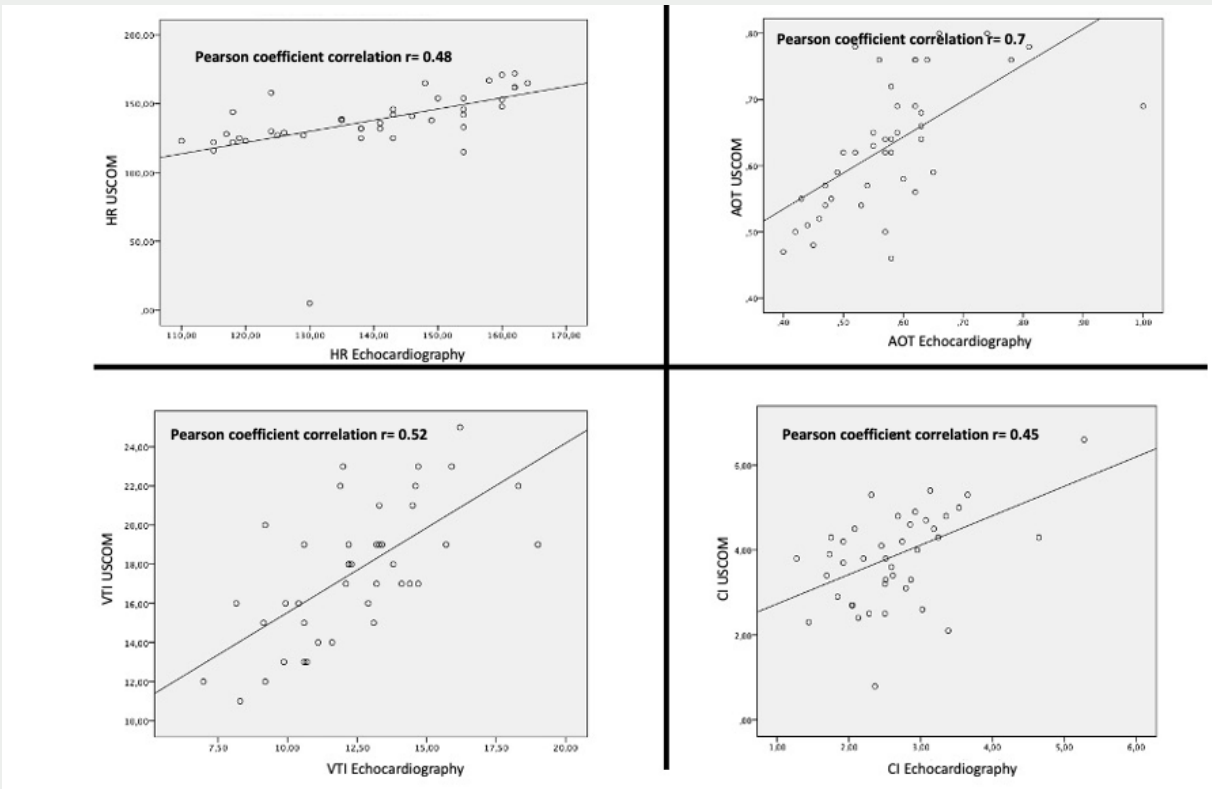

Figure 1. Pearson correlation between heart rate (HR), measured aortic outflow tract diameter (AOT), velocity time integral (VTI) and cardiac index (CI) by USCOM and TTE.

The Bland-Altman plots (Fig.2) show the agreement between USCOM and TTE for HR, AOT, VTI, and CI. The bias (mean difference) of the CI between the two methods was 1.2 l/min/m2 and the precision (± 2 SD of differences) was 1.08 l/min/m2.

The MPE of CI measurement for USCOM vs TTE was 54.9%. Calculated values of agreement between the two methods are shown in Table 2.

The intra-observer variability was very good with the two methods as the ICC was respectively of 0.98 and 0.93 for the CI measurement by USCOM and TTE.

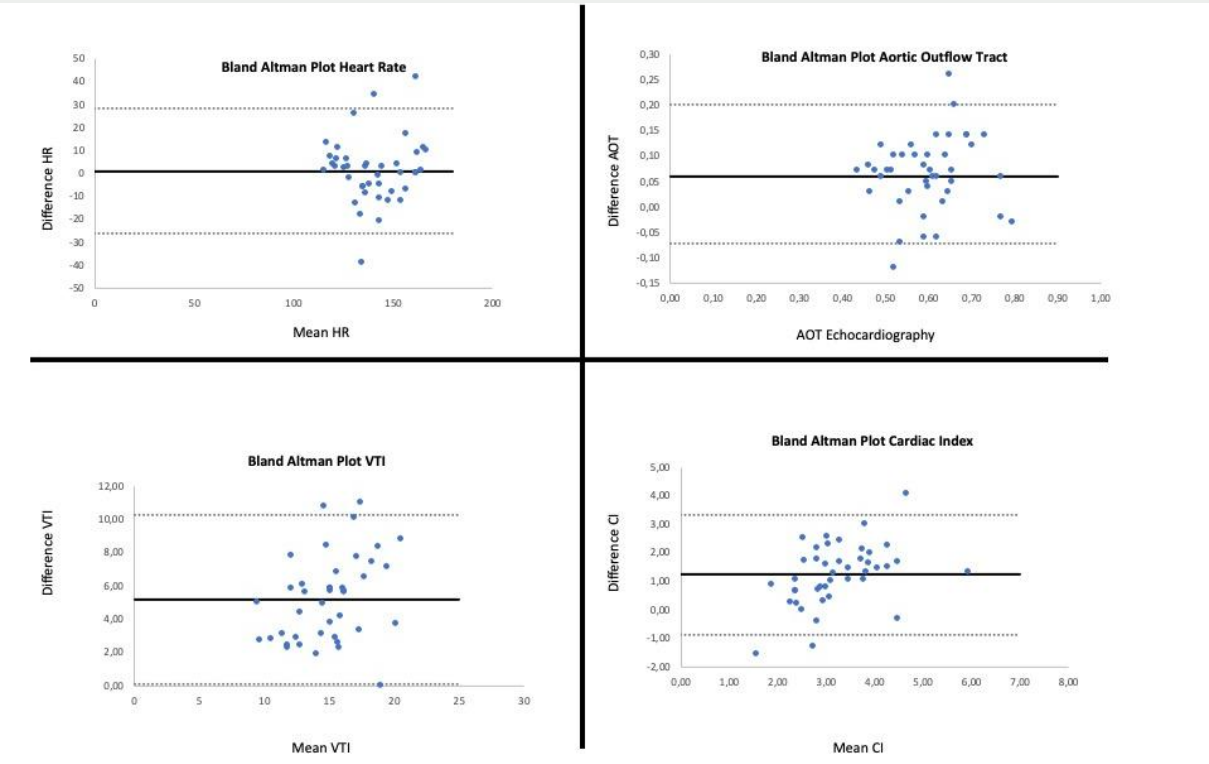

Figure 2. Bland Altman plots for heart rate (HR), aortic outflow tract diameter (AOT), velocity time integral (VTI), and cardiac index (CI)

Table 2. USCOM-1A accuracy analyses with transthoracic echocardiogram as reference standard

	Biais (SD)	Limits of agreement	MPE(%)
HR (beat/min)	1 (13.9)	(-26.3 – 28.5)	19.7
AOT (cm)	0.06 (0.07)	(-0.07 – 0.2)	21.7
VTI (cm)	5.2 (2.59)	(0.12 – 10.2)	28.7
CI (l/min/m2)	1.23 (1.07)	-0.88 – 3.34	54.3

HR: heart rate; **AOT**: aortic outflow tract diameter; **VTI**: velocity time integral; **CI**: cardiac index; **MPE** (mean percentage error)

Discussion

Our study evaluated the accuracy of the USCOM device in measuring CI to know if this technique could replace TTE in the hemodynamic assessment of critically ill neonates in our PICU.

Bland-Altman analyses showed a wide range of bias and limits of agreement between the USCOM device and TTE, with a high MPE for USCOM measurements, higher than the accepted threshold of 30 % (26).

The assessment of the agreement between the individual components of the CI showed that VTI was the main source of disagreement. Indeed, the MPE of 56.3% for VTI was well above the permitted 30% threshold, in contrast to MPE below 30% for HR (20.1%) and AOT (23.1%). We suggest that it may be due to the physiologic hyperdynamic cardiovascular state of newborn. As we chose during USCOM's measurements the FT mode, additional artifact signal produced in high-flow states may be included causing an over-measurement of USCOM's VTI. Furthermore, the measurement error inherent to the Doppler technique used in USCOM and TTE measures, may be involved through either, mal-positioning of the Doppler sample, or failure to minimize angles of insonation of the Doppler beam (18,19).

The USCOM device uses a continuous wave Doppler to measure the VTI instead of the pulsed Doppler used with TTE. Therefore, USCOM's VTI is related to the CSA of the aortic valve opening rather than to the valve annulus.

Both of the USCOM and TTE technologies are dependent on operator training and technical skill. To overcome intra-observer variability which may give some quantification of this measurement error, we performed three consecutive measurements with both USCOM and TTE. We found that the intra-observer variability was excellent with the two methods.

Our study has limitations. First, we did not exclude newborn with circulatory insufficiency, there is the potential that USCOM may perform differently in this situation. Second, we did not assess the ability of the USCOM to predict response to treatment. Finally, although previous pediatric studies (28-30) have shown a strong inter-observer reliability, we did not evaluate this aspect in our study.

It is a concern that the measurements were not made simultaneously but it is not possible to use to thoracic ultrasound devices simultaneously because of signal interference. The possibility exists that using the suprasternal USCOM could have stimulated the patient and increased VTI and cardiac output.

Few studies reported the accuracy of USCOM in pediatric population. Two studies compared USCOM to PAC thermodilution. Knirsh et al. (21) found in 22 patients with congenital heart disease undergoing interventional catheterization a bias of −0.13 l/min, limits of agreement of ±1.34 l/min and a MPE of 36.4%. They concluded that USCOM couldn't be recommended for the assessment of CO values in pediatric cardiac patients. Beltramo et al (22) found in 31 children with normal cardiac anatomy a bias of 0.2 l/min, limits of agreement between 1.2 and 1.6 l/min. Using their entire dataset and according to the method

of Critchley et al (26) the true percentage error was 33 % rather than 17% (20).

Three studies have previously compared USCOM to TTE in pediatric population. Nguyen HB et al (19) compared CI measurements by USCOM with TTE at the emergency department in 99 subjects (55 adults age 50±20 years and 44 children age 11±4 years) and observed a bias and limits of agreement of 0.58 ±2.05 l/min/m2 and MPE of 31±28%. Wongsirimetheekul et al, (18) realized paired measurements of CI in critically ill patients (aged 7.86±5.78 years). Bias±precision and percentage of error were 0.54 ±1.03 l/min/m2, 42.32% respectively. Patel N (17) assessed agreement between the 2 devices in 56 term and near-term infants, with no evidence of structural or functional cardiovascular disease, or hemodynamic shunts and found a MPE of 43%. In contrast, Pliauckiene A et al (31) found a better agreement with percentage error of 8.3 ± 6.9%. In another study, Fraga M (32), compared echocardiography to USCOM in 50 healthy newborn infants and concluded that USCOM overestimates significantly the CO.

Conclusion

Based on our findings and given the wide limits of agreement between the two methods ; USCOM and TTE cannot be considered interchangeable. USCOM cannot be recommended for the assessment of absolute CI values in pediatric patients. However, USCOM device allows quick and easy assessment of CI by the physicians with no prior experience in echocardiography with an excellent intra-observer variability. Thereby, we believe that this non- invasive monitor enables measurement of CI at an early stage in pediatric patients, before significant clinical deterioration has occurred. Further studies must determine whether USCOM's device can be reliably used as a trend monitor for CI assessment.

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