

Comparison of Continuous Cardiac Output Monitoring Derived from Regional Impedance Cardiography with Continuous Thermodilution Technique in Cardiac Surgical Patients

Abstract

Background: Cardiac output (CO) assessment is a corner stone in advanced haemodynamic management, especially in critical ill patients. The present study was conducted to validate cardiac index and cardiac output by NICaS™ with the thermodilution technique using pulmonary artery catheter in post-operative cardiac surgical patients. **Materials and Methods:** This was a prospective observational clinical study conducted at a tertiary care hospital. 23 adult patients in the age range of 18-65 years who had undergone for elective coronary artery bypass grafting were included in the study. **Results:** Spearman's correlation coefficient of cardiac index between continuous Thermodilution (cTD) and Non-Invasive Cardiac System (NICaS™) showed a good correlation ($r = 0.765$, 95% confidence interval 0.70 to 0.82, $P < 0.0001$). There was a good correlation between cTD and NICaS™ for cardiac output ($r = 0.759$, 95% confidence interval 0.69 to 0.81, $P < 0.0001$), Bland-Altman plot for cardiac index between cTD and NICaS™ showed a mean bias of -0.66 ± 0.6919 with limits of agreement being -2.02 to 0.6936 . Bland-Altman plot for cardiac output between cTD and NICaS™ showed a mean bias of -1.0386 ± 1.17 with limits of agreement being -3.34 to $+1.26$. Percentage error for cardiac index and cardiac output were 64.78% and 64% respectively. Polar plot analysis showed an angular bias of 6.32° with radial limits of agreement being -8.114° to 20.75° for cardiac index and angular bias of 5.6682° with radial limits of agreement being -9.1422° to 20.4784° for cardiac output. **Conclusion:** NICaS™ demonstrated a good trending ability for both CI and CO. However, NICaS™ derived parameters are not interchangeable with the values derived from continuous thermodilution technique.

Keywords: Cardiac index, cardiac output, continuous thermodilution technique, NICaS™

Introduction

Cardiac output (CO) assessment is a corner stone in advanced haemodynamic management, especially in critical ill patients. Currently, the average perioperative mortality after cardiac surgery is 1-2%. However, the incidence of cardiovascular morbidity remains high.^[1,2] Low cardiac-output syndrome (LCOS) is the most common and devastating complication which is characterized by reduced oxygen delivery (DO_2) and subsequent tissue hypoxia.^[3-5]

Decrease in oxygen delivery results in anaerobic metabolism leading to hyperlactatemia, which is associated with increased post-operative mortality, morbidity and hospital length of stay. Hence, monitoring CO is vital in the early detection of an imbalance between oxygen demand and oxygen delivery.

The accurate measurement of CO is obtained by gold standard intermittent thermodilution technique through a pulmonary artery catheter (PAC). The continuous thermodilution technique (cTD) has an advantage over intermittent thermodilution technique as it displays continuous measurement of cardiac output which allows the clinician to monitor the trend. Since both are invasive in nature and the indications of floating a PAC is weighed against benefits versus risks, it is often less utilized.

Due to this limitation, there is an increased research on surrogate markers of CO in terms of oxygen delivery and oxygen consumption such as mixed venous oxygen saturation, arterial lactate levels and urine output.

In recent times, there has been burgeoning interest on non-invasive CO monitors like

**Bhavya G,
Nagaraja PS,
Naveen G Singh,
Ragavendran S,
Sathish N,
Manjunath N,
Ashok Kumar K¹,
Vinayak B Nayak**

Departments of Anaesthesiology and ¹Cardiothoracic and Vascular Surgery, Sri Jayadeva Institute of Cardiovascular Sciences and Research, Jayanagar, Bengaluru, Karnataka, India

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Address for correspondence:

*Dr. Naveen G Singh,
Department of Anaesthesia,
Sri Jayadeva Institute of
Cardiovascular Sciences and
Research,
Bangalore - 560 069,
Karnataka, India.
E-mail: naveensingh@hotmail.
com*

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bioimpedance, bioreactance, applanation tonometry, partial carbon dioxide (CO₂) rebreathing, pulse wave transit time and ultrasonic methods. There have been varied results among these non-invasive CO monitors.

Non-Invasive Cardiac System (NICaS™) is a new hemodynamic navigator using the principle of bioimpedance for non-invasive measurement of CO and its derivatives. To measure CO, an alternating electrical current (1.4 mA, 30 kHz) is passed through the patient via two pairs of tetrapolar electrodes (NI Medical, Hod Hasharon, Israel). One pair of electrodes is placed on the wrist over the radial artery, and the other pair is placed on the contralateral ankle over the posterior tibial artery.^[6,7]

There is limited literature on NICaS™ derived hemodynamic parameters and its validation with invasive techniques in cardiac surgery.^[6-8]

Hence, the present study was conducted to validate cardiac index and cardiac output by NICaS™ with continuous thermodilution technique using pulmonary artery catheter in post-operative cardiac surgical patients.

Materials and Methods

This was a prospective observational clinical study conducted at a tertiary care hospital. After obtaining institutional ethical committee approval, the present study was conducted in the immediate post-operative patients.

Adult patients in the post-operative cardiac surgical unit—aged between 18 and 65 years—who had undergone elective coronary artery bypass grafting (CABG) were included in the study.

On the other hand, patients with post-operative myocardial infarction, valvular heart disease, emergency surgery, Bentall procedure, intracardiac shunts, post-operative arrhythmias, patients on Intra aortic balloon pulsation (IABP) and heart failure patients were excluded from the study.

Patients who were enrolled in the study were connected to both continuous cardiac output monitors - Continuous thermodilution technique (cTD) (Vigilance II™, Edwards Lifesciences, Irwin, USA) [Figure 1(a)] and Non-Invasive Cardiac System (NICaS™, NI medical, Petach Tikva, Israel) [Figure 1(b)]. Cardiac index (CI) and cardiac output (CO) measurements were obtained simultaneously at various time intervals until the patients were weaned from mechanical ventilation.

Hemodynamic monitoring by cTD was performed by placing pulmonary artery catheter (PAC) through right internal jugular vein whereas hemodynamic monitoring by NICaS™ was done by placing dual impedance electrodes on 2 limbs [one on volar aspect of the wrist and the other on the contralateral wrist/ankle] [Figure 2].

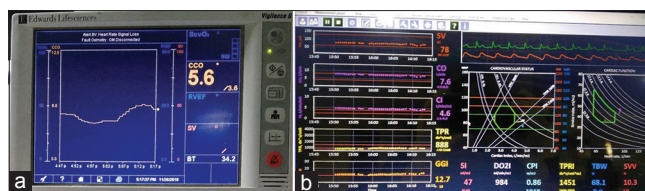


Figure 1: (a) Continuous cardiac output monitoring by Vigilance II™ monitor. (b) Continuous cardiac output monitoring by NICaS™

Statistical analysis

The results were presented as mean ± standard deviation. CI and CO values were analysed using Spearman’s correlation to determine the strength of relationship between cTD and NICaS™. Correlation coefficient values range from being negatively correlated (-1) to uncorrelated (0) to positively correlated (+1) (0.0 is no association, +0.2 is weakly positive, +0.5 is moderately positive, +0.8 is strongly positive, +1.0 is perfectly positive).

Linear regression analysis was used to create a graphic representation of the relationship with the formula of the “best fit” line allowing the CI and CO measurements of NICaS™ to be calculated from cTD. The coefficient of determination (R²) is the proportion of variation in the dependent variable (NICaS™) can be explained by a linear regression model using the independent variable (cTD).

Bland-Altman limits of agreement (LOA) plots were constructed for these data. LOA plots visually represent the bias (mean difference) and variability (95% LOA) between two methods of measurement. 95% LOA were determined by 1.96*Standard Deviation (SD) of the mean difference of CI and CO values between cTD and NICaS™. Polar plot was also been constructed to know trending ability between the two monitors.

A *P* value <0.05 was considered statistically significant. Statistical analysis was performed using MedCalc version 12.2.1.

Results

A total of 23 patients were enrolled in the study, from whom 197 data sets were been analysed. Spearman’s correlation coefficient of cardiac index between cTD and NICaS™ showed a strongly positive correlation ($r = 0.765$, 95% confidence interval 0.70 to 0.82, $P < 0.0001$). A strongly positive correlation was also observed between cTD and NICaS™ for cardiac output. ($r = 0.759$, 95% confidence interval 0.69 to 0.81, $P < 0.0001$).

Linear regression equations for CI and CO between cTD and NICaS™ were:

$y = -0.39 + 1.49x$ ($R^2 = 0.65$, $P < 0.0001$) and $y = -0.87 + 1.52x$ ($R^2 = 0.59$, $P < 0.0001$) [*y*- NICaS™; *x* - cTD], respectively.

Bland-Altman plot for CI between cTD and NICaS™ showed a bias of -0.66 ± 0.6919 with LOA being -2.02 to

0.6936 [Figure 3]. Whereas for CO bias was -1.0386 ± 1.17 with LOA: -3.34 to $+1.26$ [Figure 4].

Percentage error for cardiac index and cardiac output were 64.78% and 64% respectively. Polar plot analysis showed an angular bias of 6.32° with radial limits of agreement being -8.114° to 20.75° for cardiac index [Figure 5] and angular bias of 5.6682° with radial limits of agreement being -9.1422° to 20.4784° for cardiac output.

Discussion

The NICaSTM apparatus measures the bioimpedance of the systemic circulation and calculates the stroke volume (SV) using the Tsoglin and Frinerman formula: $SV = \Delta R/R \times \rho \times L^2/R_i \times (\alpha + \beta)/\beta \times K_w \times HF$ where ΔR is the change in impedance during the cardiac cycle (Ω), R is the basal resistance (Ω), ρ is the blood electrical resistivity, L is the patient's height, and R_i is the corrected basal resistance according to gender and age. K_w is a correcting factor for body weight, HF is a hydration factor related to the body water composition, $\alpha + \beta$ is equal to the electrocardiogram R-R interval, and β is the diastolic time interval.^[8-10]

The present study demonstrates a strong positive correlation for CI and CO with a significant coefficient of determination (R^2) for CI and CO being 0.65 and 0.59, respectively, with a P value <0.0001 which shows a good trending ability between cTD and NICaSTM monitors.

The bias for CI and CO were -0.66 ± 0.6919 and -1.0386 ± 1.17 , respectively, but with wide LOA and an increased percentage error of 64% between two monitors signifying less precision.

Anat Lavie *et al.*^[6] used the NICaSTM system to compare the hemodynamic parameters of 17 women with severe preeclampsia to a cohort of healthy normotensive pregnant women with a singleton pregnancy at term. The NICaSTM device noninvasively demonstrated low CO and high total peripheral resistance profiles in the preeclampsia group compared to control. They concluded that the NICaSTM device may help the clinician to customize the most optimal management for individual parturients.

Matsuda *et al.*^[7] evaluated NICaSTM derived CO values in 8 preoperative patients with pheochromocytoma and compared with simultaneous central blood volume (CBV) values measured by a conventional indicator dilution method using ¹³¹I - labeled human serum albumin. The NICaSTM -derived CO values significantly correlated with CBV values measured by ¹³¹I-labeled human serum albumin (4.86 ± 1.05 L/min vs 4.79 ± 1.02 L/min; $r = 0.906$; $P = 0.002$). Sequential NICaSTM derived CO values confirmed that CBV increased after preoperative treatment with an α -blocker—with or without volume loading. The results of this study indicated that NICaSTM can be used to accurately and non-invasively evaluate the hemodynamic status. By sequential monitoring of

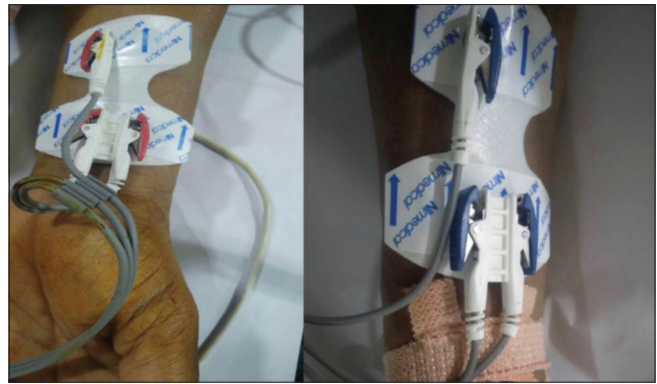


Figure 2: Placement of electrodes for NICaSTM

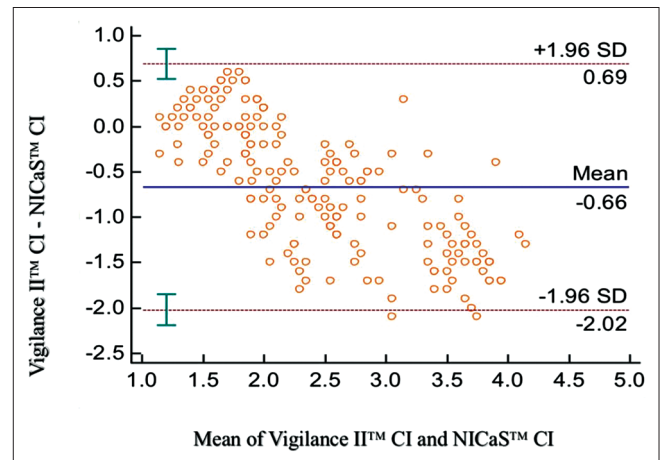


Figure 3: Bland-Altman plot to compare CI between cTD (Vigilance IITM) and NICaSTM

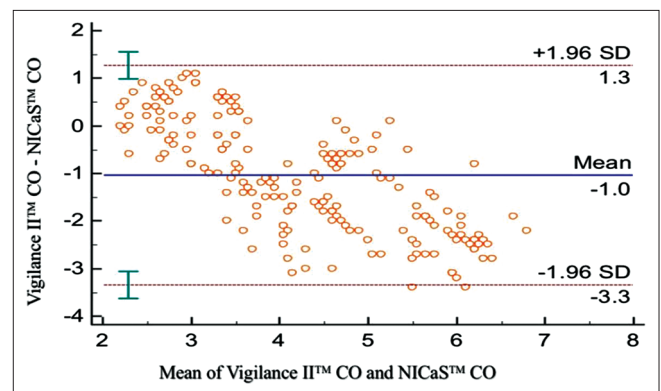


Figure 4: Bland-Altman plot to compare CO between cTD (Vigilance IITM) and NICaSTM

NICaSTM -derived CO values, the authors could confirm if adequate CBV in a patient with pheochromocytoma is obtained by preoperative medical treatment with α -blockers or volume loading, to avoid perioperative complications.

Michael J Germain *et al.*^[8] evaluated stroke volume measurements using bioimpedance cardiography and doppler echocardiography in 17 patients undergoing maintenance hemodialysis. The authors concluded that NICaSTM Stroke

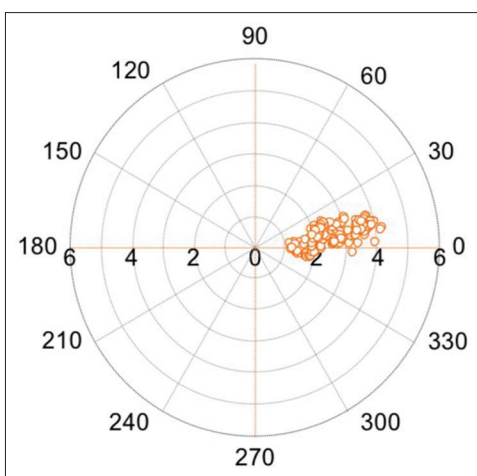


Figure 5: Polar plot analysis for cardiac index

volume (SV) measurements are similar to and strongly correlated with echocardiographic SV measurements.

B W Allwood *et al.*^[9] compared whole body impedance cardiography with thermodilution and modified Fick method of CO in 14 patients with pulmonary hypertension undergoing right heart catheterization. The authors concluded that whole body impedance cardiography may provide accurate measurements of cardiac output in patients with pulmonary hypertension and could potentially be a tool for assessing response to therapy.

Cotter MD *et al.*^[10] enrolled 122 patients in three different groups during cardiac catheterization ($n = 40$) before, during, and after coronary artery bypass surgery ($n = 51$); and while being treated for acute congestive heart failure (CHF) ($n = 31$). 418 paired CO measurements were obtained. The overall correlation between the NICaSTM cardiac index (CI) and the thermodilution CI was $r = 0.886$, with a small bias (0.0009 ± 0.684 L) [mean \pm 2 SD], and this finding was consistent within each group of patients.

Though the studies conducted by Anat Lavie *et al.*, Matsuda *et al.*, Allwood BW *et al.* and Cotter *et al.* showed good accuracy and precision using NICaSTM for guiding therapeutic intervention which is not in agreement with the present study. Critchley *et al.* has demonstrated that polar plot analysis showing an angular bias of $<5^\circ$ and radial limits of agreement $\pm 30^\circ$ have good trending ability of the monitor.^[11] In the present study, polar plot analysis showed an angular bias of 6.32° with radial limits of agreement being -8.114° to 20.75° for cardiac index and angular bias of 5.6682° with radial limits of agreement being -9.1422° to 20.4784° for cardiac output.

Conclusion

NICaSTM demonstrated a good trending ability for both CI and CO. However, NICaSTM derived parameters are not interchangeable with the values derived from continuous thermodilution technique.

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Conflicts of interest

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