



COMPARISON OF NON-INVASIVE (esCCO) AND INVASIVE (PAC-CCO) METHOD OF CARDIAC OUTPUT ASSESSMENT IN PATIENTS UNDERGOING ELECTIVE CORONARY ARTERY BYPASS GRAFTING SURGERY

Anaesthesiology

Dr Amol B. Thakre	Associate Professor, Department of Anaesthesia, Government Medical College, Chandrapur
Dr Ketki A. Ramteke	Assistant Professor, Department of Anaesthesia, Government Medical College & Super-Specialty Hospital, Nagpur
Dr Yogesh N. Zanwar*	Assistant Professor, Department of Anaesthesia, Government Medical College & Super-Specialty Hospital, Nagpur *Corresponding Author
Dr Vijay R. Shrotrye	Professor & Head, Department of Anaesthesia, Government Medical College & Super-Specialty Hospital, Nagpur

ABSTRACT

Background: Measurement of cardiac output helps in prompt management of hemodynamic disturbances in the perioperative period as well as in critical patients. There are various methods for monitoring of cardiac output, out of which thermodilution (PAC guided) method (PAC-CCO) is considered gold standard. We compared the purely non-invasive (esCCO) and invasive (PAC-CCO) methods of cardiac output assessment in elective coronary artery bypass grafting (CABG) cases.

Methods: In this prospective observational study of 6 months duration, 35 patients posted for elective CABG at our centre were studied.

Results: Out of 498 datasets obtained, there were same readings in only 5 datasets. 135 datasets gave lower estimation and 358 datasets give higher estimation. The mean values for cardiac output in invasive and non-invasive cardiac output were 4.4 and 4.97 lit/min (mean statistically significant difference of 0.57 lit/min). The datasets showed significant correlation between invasive and non-invasive cardiac output ($p < 0.001$, $r = 0.72$).

Conclusion: Cardiac output assessed with non-invasive method showed higher as well as lower estimates, but chances of higher estimates are more. The non-invasive (esCCO) method of cardiac output estimation showed strong correlation with gold standard Invasive (PAC-CCO) method.

KEYWORDS

Cardiac output monitoring, invasive, non-invasive, CABG

INTRODUCTION-

Cardiac output is one of the key entity to be monitored in contemporary practice of anaesthesiology in general & cardiac anaesthesiology in particular. Measurement of the cardiac output and other derived variables helps anaesthesiologists to treat hemodynamic disturbances in the perioperative period. It is also an important parameter to be monitored in high risk surgical patients & critically ill patients in intensive care units. There are various methods for monitoring of cardiac output, out of which thermodilution (PAC guided) method (PAC-CCO) is considered as gold standard.^{1,4} Over the past decade or so, various other methods for cardiac output estimation were also developed.⁵ Some of which are pulse contour cardiac output (PiCCOTM), Lithium dilution cardiac output (LIDCO), USG guided estimation and oesophageal Doppler.

Low cardiac output is detrimental. Low-cardiac-output syndrome is the most common and the most serious complication and is associated with increased morbidity, short- and long-term mortality, and healthcare resource utilization.^{6,7} Section of critically ill patients who are unable to sustain a cardiac index in excess of 2 l/min/m^2 , despite aggressive therapy, have reportedly very high mortality rate.⁸ In many of these patients the cause of the low cardiac output is inadequate cardiac filling, which is responsive to fluid resuscitation. Measurement of cardiac output is indicated as an aid to prognosis and diagnosis, and to monitor the adequacy of therapy.⁸

Ideally cardiac output measurement should be accurate, non-invasive and should give continuous readings. Most of the methods of cardiac output estimation are invasive or minimally invasive, need technical skills & are complications prone.⁵ Recently, some new techniques are introduced which claim to estimate cardiac output noninvasively, viz. thoracic electric bioimpedance, transthoracic echocardiography, oesophageal Doppler etc.⁵ A new term, "pulse wave transit time" (PWTT), has come up recently. PWTT uses correlation of the heart activity to the electrocardiogram (ECG). It measures time taken by the pulse (heartbeat) to propagate to another sensor on the arm, finger or leg. This sensor can be saturation of peripheral oxygen (pulse oximeter, SpO₂) or non-invasive blood pressure (NIBP) sensor.⁵ Estimated continuous cardiac output (esCCO) is a technique that further uses this timing to measure CO on a continuous yet completely non-invasive principle.

We aimed to compare this non-invasive (esCCO) and invasive (PAC-CCO) methods of cardiac output assessment in coronary artery bypass grafting (CABG) cases at our centre.

MATEREIALAND METHODS-

Type of study- Prospective observational study

Study setting- Super-Specialty Hospital, Government Medical College & Hospital, Nagpur

Study duration- Six months

Sample Size- Thirty-five patients (recruited by consecutive sampling)

Inclusion criteria-

- All patients posted for elective CABG surgery during study period
- Patients in sinus rhythm
- Willing to give consent for the study

Exclusion criteria-

- Patients with arrhythmias
- Patients with valvular heart disease
- Patients preoperatively on inotropic support
- Patients preoperative on ventilator support
- Preoperative renal hepatic dysfunction
- Patients with peripheral vascular disease
- Patients requiring emergency surgery
- Patients requiring intra-aortic balloon pump or requiring circulatory support during the intraoperative period

Procedure-

All the data sets were collected during intraoperative period as there is more manipulation of heart during off pump CABG surgeries causing maximum variation in cardiac output in short span of time. For the surgical procedure a balanced anaesthesia technique using Fentanyl (3-5 ug/kg), Midazolam (0.04-0.08 mg/kg) and Vecuronium (0.15-0.2 mg/kg) was used. After taking informed consent for operation, patient was wheeled inside theatre. Patients were pre-medicated with Fentanyl 1 µg/kg and Midazolam 0.05 mg/kg. Peripheral venous access with 16 G IV cannula was secured. Right radial and left femoral arteries were cannulated. Right internal jugular vein was cannulated with 8.5 fr. sheath for PAC. A 7.5 fr. combo catheter (Edward Lifesciences) was

inserted through the sheath and position was confirmed with the waveform appearance on monitor. Cardiac output monitoring was started with thermodilution technique (Vigilance II Monitor, Edwards Life sciences, USA). esCCO monitor (Lifescope monitor) consists of ECG leads, SPO2 sensor and NIBP cuff attached to the patient. Non-invasive cardiac output monitoring was started with it. The esCCO system estimates the PWTT from the time gap between ECG-R wave and the peripheral pulse detected by the pulse oximeter. The principle of esCCO is an inverse correlation between stroke volume (SV) and PWTT. Based on this principle, esCCO is calculated by the following equation:

$$EsCCO = K \times (\alpha \times PWTT + \beta) \times \text{heart rate}$$

(Where α is a fixed value which is decided experimentally by the past esCCO clinical studies).

The constants K and β are individualized for each patient. These values are dependent on physical profile (age, weight, height) of the patient. The present protocol (software) tends to negate the effect of the change of vascular properties (vasoconstriction or arteriosclerosis) on the effect of travel time of pulse wave thus reflecting changes in SV alone to measure the cardiac output.

For esCCO measurement monitor, we calibrated blood pressure with invasive arterial line. Demographic data was entered into monitor (age, weight, height, gender). After this monitor calculates esCCO on the basis of data entered. Data set collected from both monitors at identical time at 15 min interval simultaneously. After establishing all monitors, the patients were induced with balanced general anaesthesia technique. Patients were maintained on controlled ventilation 0.5 % Fio2 air-oxygen mixture and continuous infusion of Atracurim/Fentanyl bolus and inhalational Isoflurane. After sternotomy LIMA was harvested & heparinised with 2 mg per kg heparin. During grafting ACT was maintained more than 300 seconds all time. First LIMA was anastomosed with LAD. Subsequently distal grafting to OM, PDA or distal RCA was done as per patients disease process involvement aided by coronary angiography report. After that proximal anastomosis to aorta was done. Half dose protamine reversal was done. During intraoperative period hemodynamics was maintained with fluid bolus & table tilting. Noradrenaline and Dobutamine were used as per patient's hemodynamic need.

Institutional Ethics Committee approved the study. The data were analysed using SPSS version 17.

RESULTS-

The study participants were mostly males (80%) and with mean age of 57.5 years. The basic demographics of the study participants is given in table 1.

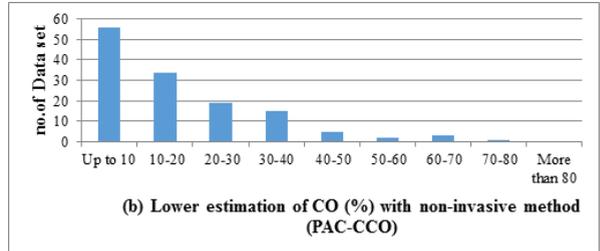
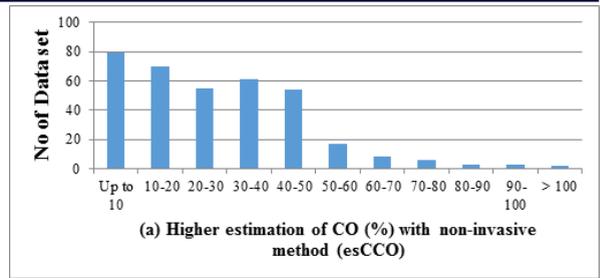
Table 1: Basic demographics of the study participants

Parameter	Mean (SD)	Minimum	Maximum
Age (Years)	57.54 (8.62)	40	78
Gender			
Male	28 (80)		
Female	7 (20)		
Height (cm)	172		
Weight (kg)	65.8	45	96

A total of 498 data sets were obtained from 35 patients studied over 6 months. Out of these 498 datasets, we had same (invasive/non-invasive) readings in only 5 datasets. 135 datasets gave lower estimation and 358 datasets give higher estimation of cardiac output in non-invasive monitor than invasive method. The mean values for cardiac output in invasive and non-invasive cardiac output were 4.4 and 4.97 lit/min (mean difference of 0.57 lit/min) with standard deviation of 1.47 and 1.75 respectively.

Chart 1 shows frequency distributions of lower (a) & higher (b) estimation of cardiac output in non-invasive (esCCO) than invasive (PAC-CCO) methods.

Chart 1- Frequency distributions: (a) Lower estimation of cardiac output in non-invasive (esCCO) than invasive (PAC-CCO) methods (n = 135). (b) Higher estimation of cardiac output in non-invasive (esCCO) than invasive (PAC-CCO) methods (n = 358)

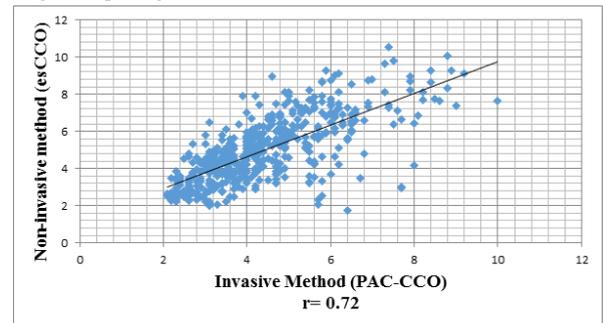


The number of data sets went on increasing with each categorical increase (by 5%) in clinical acceptable range of change in CO. (Table 2)

Table 2. Number of data sets in clinically acceptable range of change in CO

Acceptable change in CO	Data sets
Up to +/- 5 %	76
Up to +/- 10 %	140
Up to +/-15 %	194
Up to +/- 20%	244

The datasets showed significant correlation between invasive and non-invasive cardiac output (p<0.001, r = 0.72). Figure 1 shows the scatter diagram depicting same.



DISCUSSION-

In this prospective observational study of 6 months duration, 35 patients posted for elective CABG at our centre were studied. We chose off-pump elective CABG patients for this study, as it was thought that the variations in cardiac output are higher in this type of surgery due to change in positioning during grafting.

The present study shows CO difference of only 0.57 lit/min. It is noteworthy that; the difference, although small, is statistically significant. It is also important to note that the values we obtained are both higher and lower than the gold standard i.e. thermodilution method (the matching CO readings in both invasive & non-invasive methods were present in only 5 out of total 498 data sets).

Ball and colleagues⁹ in patients undergoing cardiac surgery reported mean bias value of 0.80 L/min with 95% CI of 2.00-3.61 L/min. They concluded that esCCO is easy to use and provides continuous CO measurements, but has wide limits of agreement and large percentage errors with a consistently positive bias in comparison to the thermodilution method. Whereas, we report both positive as well negative comparative values in this study. They also similarly challenged the clinical utility of esCCO method because of large variations in the level of agreement of both the tests. According to meta-analysis by Critchley¹⁰, using current reference methods, acceptance of a new technique should rely on limits of agreement of up to +/-30%.

In our study, the datasets showed significant correlation between invasive and non-invasive cardiac output ($r = 0.72$). In a similar study by Sinha et al¹¹, significant correlation ($r = 0.6$, $P < 0.001$) was noted. The difference of 12 percentage points between the studies may be explained by the non-exclusion of patients with valvular heart disease in the Sinha study. Further, according to studies conducted by Ishihara and colleagues¹², though the linear correlation between esCCO and thermodilution did improve by new model based on an exclusion algorithm for patients after analysing high error rates found in previous data (r^2 values improved from 0.57 to 0.64), the percentage of error remains high to be accepted clinically. Other argument in favour of esCCO measurement is, it's completely non-invasive nature. But this advantage is nullified by errors in values of cardiac output.

Fischer et al¹³ showed that cardiac output measured by esCCO and TTE vary considerably after giving fluid boluses. Thus its clinical utility with such a large degree of potential error is debatable.

Comparison of esCCO with other non-invasive method also shows poor outcome of study. Bataille et al compared cardiac output by esCCO and trans-thoracic echocardiography in critically ill patients.¹⁴ They concluded that the performance of the esCCO monitor was not clinically acceptable, and this monitor cannot be recommended.

Moreover, the esCCO routinely fails to trend CO data reliably in the various studies. The basic design of esCCO system, which relies upon the time for pulse wave to travel from the heart to peripheral vessel where the sensor is used, could be at fault here. This is since any anatomical (body habitus) differences are obviously likely to effect the duration for pulse travel time. Other possible limitations that exist with the present measurement protocol are that a stenotic valve can significantly lower the pulse generation speed, whereas the regurgitant lesion generates fast but small volume pulse. In present study, we have tried to account for this possible fallacy with all the patients of valvular heart disease.

Our observations collectively do provide statistically significance in a clinical scenario; where a decision has to be made on cardiac output monitoring, these differences can produce a serious error in judgement like over-transfusion leading to pulmonary oedema or over use of inotropes further increasing the cardiac workload. Thus the usage of esCCO in routine monitoring cannot be warranted due to the discussed factors.

We conclude by saying that cardiac output assessed with non-invasive (esCCO) method showed higher as well as lower estimates, but chances of higher estimates are more. The non-invasive (esCCO) method of cardiac output estimation did show strong correlation with gold standard Invasive (PAC-CCO) method in patients undergoing elective coronary artery bypass grafting surgery, but the percentage of error remains high. The fact that we only included only elective CABG patients & that the calibrations were done w.r.t. invasive blood pressure limit the generalizability of our observations to some extent though.

DECLARATIONS:

Funding: Self-funded by the authors

Conflict of interest: None

REFERENCES-

1. Tsutsui M, Mori T, Aramaki Y, Fukuda I, Kazama T. A comparison of two methods for continuous cardiac output measurement: Pulse CO Vs CCO. *Masui* 2004; 53: 929-33.
2. Schulz K, Abel HH, Werning P. Comparison between continuous and intermittent thermodilution measurement of cardiac output during coronary artery bypass operation. *Anaesthesiol Intensivmed Notfallmed Schmerzther* 1997; 32: 226-33.
3. Jonas MM, Tanser SJ. Lithium dilution measurement of cardiac output and arterial pulse waveform analysis: an indicator dilution calibrated beat-by-beat system for continuous estimation of cardiac output. *Curr Opin Crit Care* 2002; 8: 257-61.
4. Su NY, Huang CJ, Tsai P, Hsu YW, Hung YC, Cheng CR. Cardiac output measurement during cardiac surgery: esophageal Doppler versus pulmonary artery catheter. *Acta Anaesthesiol Sin* 2002; 40: 127-33.
5. Jozwiak M, Monnet X, Teboul J-L. Monitoring: From cardiac output monitoring to echocardiography. *Curr Opin Crit Care* 2015; 21: 395-401.
6. Maganti MD, Rao V, Borger MA, et al. Predictors of low cardiac output syndrome after isolated aortic valve surgery. *Circulation* 2005; 112: 1448-452.
7. Maganti M, Badiwala M, Sheikh A, et al. Predictors of low cardiac output syndrome after isolated mitral valve surgery. *J Thorac Cardiovasc Surg* 2010; 140: 790-6.
8. Rihal CS, Naidu SS, Givertz MM, et al. 2015 SCAI/ACC/HFSA/STS Clinical Expert Consensus Statement on the Use of Percutaneous Mechanical Circulatory Support Devices in Cardiovascular Care: Endorsed by the American Heart Association, the Cardiological Society of India, and Sociedad Latino America. *J Am Coll Cardiol* 2015; 65: e7-26.
9. Ball TR, Tricimella AP, Kimbrough BA et al. Accuracy of noninvasive estimated continuous cardiac output (esCCO) compared to thermodilution cardiac output: a pilot study in cardiac patients. *J Cardiothorac Vasc Anesth*. 2013 Dec; 27(6):1128-32.
10. Critchley LA, Critchley JA. A meta-analysis of studies using bias and precision statistics to compare cardiac output measurement techniques. *J Clin Monit Comput*. 1999 Feb; 15(2):85-91.
11. Sinha AC, Singh PM, Grewal N, Aman M, Dubowitz G. Comparison between continuous non-invasive estimated cardiac output by pulse wave transit time and thermodilution method. *Ann Card Anaesth* 2014; 17: 273-7.
12. Ishihara H, Sugo Y, Tsutsui M et al. The ability of a new continuous cardiac output monitor to measure trends in cardiac output following implementation of a patient information calibration and an automated exclusion algorithm. *J Clin Monit Comput*. 2012 Dec; 26(6):465-71.
13. Fischer MO, Balaire X, Le Mauff de Kergal C et al. The diagnostic accuracy of estimated continuous cardiac output compared with transthoracic echocardiography. *Can J Anaesth*. 2014 Jan; 61(1):19-26.
14. Bataille B, Bertuit M, Mora M et al. Comparison of esCCO and transthoracic echocardiography for non-invasive measurement of cardiac output intensive care. *Br J Anaesth*. 2012 Dec; 109(6):879-86.