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BRIEF REPORT

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Continuous cardiac output monitoring after cardiopulmonary bypass: a comparison with bolus thermodilution measurement

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Abstract *Objective:* The interchangeability of continuous measurement of cardiac output (CO) with the traditional bolus method in patients after cardiopulmonary bypass (CPB) is uncertain. *Design:* Prospective observational clinical study. *Setting:* A 20-bed surgical ICU at a university hospital. *Patients:* Fourteen deeply sedated, ventilated, post-cardiac surgery patients, all equipped with a pulmonary artery catheter. *Interventions:* Six hours after the end of the CPB, 56 simultaneous bolus and continuous measurements were compared by a linear regression analysis and Bland–Altman analysis. Bolus CO was estimated by averaging triplicate injections of 10 ml room-temperature NaCl 0.9%, delivered randomly during the respiratory cycle. A stringent maximum difference of 0.55 $l\,min^{-1}$ (about 10% of the mean bolus measured) was considered as a clinically acceptable agreement between the two types of measurements. To be interchangeable the limits of agreement (± 2 SD of the mean difference between the two methods) should not exceed the chosen acceptable difference. *Measurements and results:* Continuous was correlated with bolus CO, with a correlation coefficient of $r^2 = 0.68$. ($p < 0.01$). The Bland–Altman analysis demonstrated an objective mean bias of $0.33 \pm 0.6\ l\,min^{-1}$ (confidence interval of –0.87 – 1.58) with 34% of measured values falling outside of the clinically acceptable limits. *Conclusion:* Our results suggest that, in the first 6 h after CPB, continuous and bolus CO determinations are not interchangeable; one third of the values obtained by continuous CO fell outside the strict limits of clinically useful precision.

Keywords Cardiac surgery · Hypothermia · Swan–Ganz catheter

Abbreviations *BCO:* Bolus cardiac output · *CCO:* Continuous measurement of cardiac output · *CO:* Cardiac output · *CPB:* Cardiopulmonary bypass · *PAC:* Pulmonary artery catheter

Introduction

The precise evaluation of hemodynamic variables is often necessary to manage unstable patients in a surgical intensive care unit. Among them, cardiac output (CO) monitoring allows assessment of cardiac function and the calculation of vascular resistance, global oxygen delivery and consumption. The standard method for CO assessment still remains the intermittent determination using the bolus thermodilution technique (BCO), which has proven to be precise enough for clinical application [1]. Recently, a pulmonary artery catheter (PAC) equipped with a special thermal filament has allowed continuous cardiac output measurement (CCO) [2]. Compared to BCO, CCO has obtained promising results [2, 3].

To our knowledge few studies, with conflicting results, have investigated the interchangeability of CCO with BCO measurements in patients submitted to a cardiopulmonary bypass (CPB) [4, 5]. The aim of this prospective clinical study was to determine the comparability of CCO using an optical fiber catheter with the traditional BCO measurement in the early phase after cardiac surgery with CPB. The authors' hypothesis was that mild hypothermic CPB may affect the accuracy of CCO measurement in the first few hours following CBP (unsteady-state thermal regulation) [5].

Materials and methods

The study was approved by our institutional ethics committee. Only patients scheduled for coronary artery bypass graft (CABG) surgery were prospectively screened. Exclusion criteria were: (1) decreased left ventricular ejection fraction ($< 45\%$) and (2) valvular disease. Postoperatively, patients presenting severe hemodynamic instability and/or bleeding greater than 100 ml/h were also excluded.

Postoperative management

Perioperative management was as previously described [6]. The CPB flow was set at 2 $l\,min^{-1}.m^{-1}$ After surgery, the patients were placed on mechanical ventilation. Body temperature, ECG and urine output were monitored throughout the postoperative period. Before the study period, patients were observed for at least 2 h to confirm hemodynamic stability, which was defined as a less than 10% change in heart rate, mean arterial pressure, CO and SvO_2.

Hemodynamic measurements and study protocol

All pressure transducers were referenced to the mid-chest. The correct position of the PAC (CCOmbo, Edwards Lifesciences, Irvine, CA, USA) tip in West's zone III was checked using a method previously described [7]. Thereafter, the PAC was connected to the monitor (Vigilance, Edwards Lifesciences, Irvine, CA, USA). Simultaneous measurements of CCO and BCO were taken. Values of CCO were obtained before BCO measurements, as CCO is interrupted during the bolus injection. BCO was estimated by averaging triplicate injections of 10 ml room-temperature NaCl 0.9%, delivered randomly during the respiratory cycle.

Statistical analysis

The results are expressed as mean ± standard deviation (SD). The values of CCO and BCO were compared by linear regression. A Bland–Altman analysis was used to estimate the bias between the two methods. Bias, the limits of agreement (± 2 SD) and the percentage error were calculated [8]. The percentage error was calculated as the ratio between the limits of agreement (i.e., 2 SD of the bias) divided by the CO (calculated as the mean of both methods). In order to obtain results that would be clinically comparable, we determined using the method described by Critchley and Critchley [9] and LaMantia et al. [10] a maximal limit of ± 10% of the mean BCO measured as an acceptable difference between the two measures. Statistical analyses were performed using Graph Pad Prism (Graph pad software V3, San Diego, CA, USA) for PC. A p value < 0.05 was considered statistically significant.

Results

Fourteen patients (11 males and 3 females, age 63 ± 9 years) were included in this study. The mean CPB duration was 106 ± 42 min and the aortic cross-clamp time 71 ± 33 min. Mean body temperature was 37 ± 0.6°C. The mean values of CCO and BCO were 5.8 ± 1.1 $l\,min^{-1}$ (minimum 4.3, maximum 8.7) and 5.5 ± 0.9 $l\,min^{-1}$ (minimum 3.7, maximum 8.2) respectively. Thus, the limit of 0.55 $l\,min^{-1}$ (10% of the mean BCO) was used as an acceptable difference between the two measurements.

Fifty-six simultaneous measurements of CCO and BCO were obtained (4 measurements per patient every 30 min). Six measurements of BCO in 5 patients were excluded due to a signal defect. All measurements were performed between 4 h and 8 h after the end of CPB.

The mean and median differences between the two measurements were 0.33 (SD 0.6) $l\,min^{-1}$, and 0.28 (range

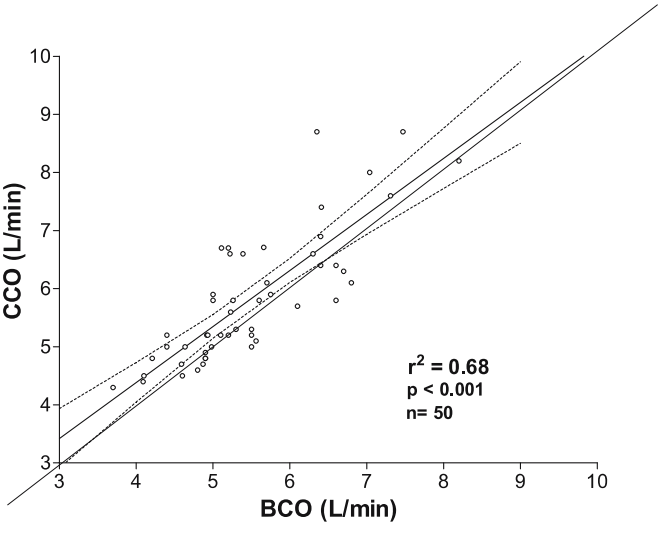

Fig. 1 Linear correlation between CCO and BCO. Linear regression analysis (*solid line*), identity line value (*dashed line*) and 95% confidence intervals (*dotted lines*) are indicated

–0.8 to +2.35) $1\,min^{-1}$, respectively. The comparison between CCO and BCO by linear regression shows a correlation coefficient $r^2 = 0.68$ ($p < 0.01$) (Fig. 1). The Bland–Altman analysis reveals a mean bias of 0.33 $\pm$ 0.6 $1\,min^{-1}$ (95% confidence interval –0.87 to 1.58) (Fig. 2a). The percentage error (see definition) was 22% [8]. To account for dependence in the data, we took the average of the four measures within each subject and found a nonsignificant difference in correlation and bias (Tukey's multiple comparison test, $p = 0.66$; see electronic supplementary material). Seventeen measures (34%) fell out of the clinically acceptable range of 10% of mean BCO. The relative Bland–Altman analysis reveals a mean bias of 5.58 $\pm$ 10.3 % (95% confidence interval –15% to 26.2%) (Fig. 2b). Fifteen measures (30 %) fell out of the clinically acceptable range of 10% of mean BCO. However, if a less strict clinically acceptable range (i.e., 20% of mean BCO) is chosen, only two measures (4%) fell out of the clinical acceptable range.

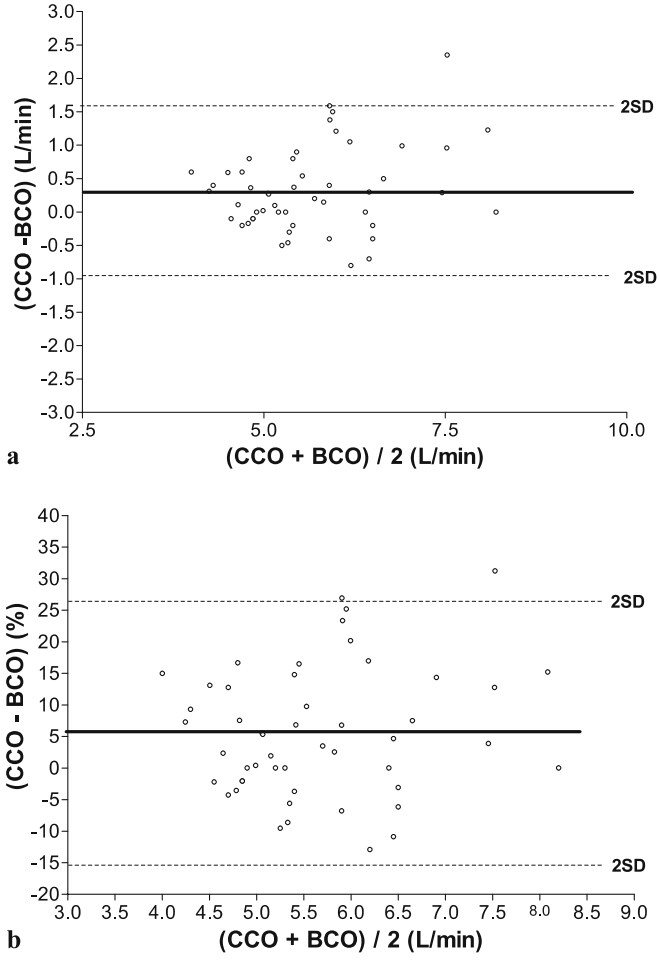

Fig. 2 **a** Bland–Altman analysis of agreement between CCO and BCO. The middle *solid line* indicates the average differences between the two methods (bias), while the outer *dashed lines* represent 2 SD. **b** Relative Bland–Altman analysis of agreement between CCO and BCO (bias in % calculated as (100 × bias/mean CO of both methods). The middle *solid line* indicates the average differences between the two methods (bias), while the outer *dashed lines* represent 2 SD

Discussion

The objective of the present study was to determine the comparability between CCO using an optical fiber catheter and traditional BCO measurement in patients after CABG involving CPB. The data show that CCO is reasonably correlated to BCO ($r^2 = 0.68$; $p < 0.01$) but with a wide confidence interval (–0.87 to 1.58). Moreover, 34% of the values were outside the clinically tolerable range of 10% difference between the two methods.

Hemodynamic monitoring of patients undergoing cardiac surgery using PAC is safe and still largely used [11, 12]. However, even if CCO monitoring has no advantage over BCO regarding the risk of bacterial contamination [13], continuous observation of cardiac function by CCO allows immediate detection of changes in CO following (1) changes in mechanical ventilation setting, (2) an early undiagnosed hemorrhage and/or (3) a cardiac tamponade. Few studies have compared the continuous with the traditional bolus method in the post-operative period after cardiac surgery involving CPB. A French study including 44 patients scheduled for elective mitral and/or aortic valve surgery under mild hypothermic CPB showed a satisfactory correlation between CCO and BCO ($r^2 = 0.83$), with a bias of 0.066 $\pm$ 0.53 [4]. Bottiger and co-workers showed a good correlation and precision between CCO and BCO in 30 cardiac surgery patients before CPB and more than 45 min after hypothermic CPB ($r^2 = 0.76$; $p < 0.01$), but a lack of correlation in the early phase after CPB ($r = 0.3$) [14]. In the present investigation, we noted a correlation coefficient of 0.82 with a high mean bias, suggesting that CCO and BCO are not interchangeable. Indeed, 34% of all value obtained were outside a clinically tolerable range. Our data are in agreement with those of Zollner et al., who also studied patients after cardiac surgery and found that about 50% of all data points were outside a predefined clinical range [5].

It is essential to state that CCO assessment is an averaging technique. The value indicated by the device is a mean value reflecting the data collected in the past 3–6 min. Thus, more rapid changes in CO could not be reflected by CCO data with the current software version [15]. Others limits for such investigations have been well documented [16, 17, 18] in this patient population, including pulmonary artery thermal instability and background noise caused by the hypothermic CPB and mechanical ventilation. In addition, when comparing the two methods, the limits of agreement of their difference need to be larger than the limits of precision of the reference method [10]. Unfortunately, we have no better

mean for comparisons with new methods than the traditional "standard" BCO, which has its own limitations and measurement error (10%, reproducibility 0.5 l min^{-1}) [1]. Thus, we determined beforehand a maximal limit of 10% for the mean BCO (0.55 l min^{-1}). To our knowledge, the study by Zollner et al. is the only published investigation reporting a similar comparison [5].

Some limitations of this work should be acknowledged. First, in view of the small sample size, its clinical relevance could be questioned. Second, the present study is limited by the fact that no measurements were performed in the late phase of CPB to investigate whether this observation is time related and/or whether this phenomena persists after CPB. Third, in the present study, patients with decreased pre-operative left ventricular ejection fraction ($< 45\%$) and moderate and severe valvular disease were excluded, and the results may not be generalizable to this population. Fourth, as observed in our results, the conclusion of the present study is based on a strict clinically acceptable limit threshold of 10%. And undeniably, if the clinically acceptable limit chosen were fixed at 20% or higher the agreement between the two methods would be adequate. Finally, comparative data in cardiac surgical patients without CPB (beating heart) would also been beneficial to determine whether this observation is exclusively related to CPB.

In conclusion, the present study indicates that, compared to BCO measurement in the 6-h window after CPB, CCO assessment provides values which are beyond clinically useful precision of 10% in one third of cases.

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