原 著

The Accuracy of Continuous Thermodilution Method in Comparison with Bolus Cardiac Output Measurement Using Room Temperature Versus Cold Injectates in Cardiac Surgical Patients

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Abstract

We studied 21 adult cardiac surgical patients to assess the accuracy of continuous thermodilution method in comparison with bolus cardiac output measurement using room temperature versus cold injectates. An 8-French gauge thermal filament-wrapped, flow directed, pulmonary artery catheter was placed and connected to a computer system to measure continuous cardiac output (CCO) automatically. Both CCO and bolus cardiac output (BCO) measurements were performed at stable conditions after induction of anesthesia and also after weaning from cardiopulmonary bypass in each patient. As BCO measurement, 10 ml of ice-cold solution (BCO-IC) or room-temperature solution (BCO-RT) were injected using a closed delivery system with in-line temperature measurement. A total of 41 measurements were carried out. BCO-IC ranged from 2.2 to 9.7 L/min, BCO-RT from 2.1 to 9.9 L/min, and CCO from 2.3 to 12.4 L/min. Regression analysis demonstrated a close relationship between either two of three methods; correlation coefficients of [BCO-IC−BCO-RT], [BCO-IC−CCO], and [BCO-RT−CCO] were 0.986, 0.962 and 0.962, respectively. By the Bland and Altman analysis, biases (mean differences) were negligible among the three measurements (0.10–0.38 L/min), although precisions (standard deviation of differences) between [BCO-IC−CCO] (0.59 L/min) and [BCO-RT − CCO] (0.59 L/min) were slightly larger than that between [BCO-IC − BCO-RT] (0.31 L/min). In conclusion, CCO methods are practically acceptable during cardiac surgery, and BCO-RT is equivalent in accuracy with BCO-IC, suggesting that BCO-RT can be used instead of BCO-IC because it is more convenient and less expensive.

Key words; pulmonary arterial catheter, cardiac output measurement, continuous cardiac output measurement, bolus cardiac output measurement

Introduction

Accurate assessment of cardiac output is important in the intra-operative management of cardiac surgical patients. Anesthesiologists have to adjust the circulatory status to an optimal condition by choosing either vasopressors, vasodilators or inotropic agents based on the meticulous evaluation of hemodynamic parameters obtained by cardiac output measurements.

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Although several invasive and noninvasive methods have been proposed for the measurement of cardiac output, such as dye and thermal dilution techniques, electrical impedance, and echo Doppler techniques[1~3], the most reliable and widely accepted method for measuring cardiac output during surgery is the thermodilution technique, which involves intermittent bolus cardiac output measurement (BCO) and continuous cardiac output measurement (CCO) with a thermal filament-wrapped pulmonary artery catheter[3,4].

Many studies have proved a good correlation between iced and room temperature bolus cardiac output measurements[5~7] in critically ill patients, resulting in the current routine use of room temperature (RT) injectate for assessing cardiac output in clinical practice. As for the comparison between BCO and CCO, the bias and precision are not always consistent among the clinical studies, ranging from excellent[8~10], acceptable agreement[11], to no agreement[12]. The inconsistency may be due to techniques of injection, the temperature and volume of the injectate, and the difference of body temperature. There have been few studies to compare simultaneously three measurements, CCO and BCO with cold and room temperature injectates, in cardiac surgical patients.

The aim of the present study was to investigate the accuracy and precision of the CCO technique in comparison with BCO measurements using cold and room temperature injectates.

Materials and methods

We studied 21 adult patients (16 males and 5 females) undergoing cardiac surgery who matched our institutional indications of cardiac output measurement. Anesthesia was induced with fentanyl (5–10 μg/kg) and midazolum (0.05–0.15 mg/kg). After endotracheal intubation under muscle relaxation with vecuronium (0.1 mg/kg), anesthesia was maintained with continuous infusion of propofol (2–3 mg/kg/hr) and intermittent infusion of fentanyl (1–2 μg/kg), with sevoflurane (1.0–2.0%) if necessary.

Through the right internal jugular vein an 8 French gauge thermal filament-wrapped, flow directed, pulmonary artery catheter (Edwards Lifesciences, Irvine, CA, USA) was placed under guidance of pressure waves. An appropriate position of the catheter was confirmed by chest X-ray.

A computer system (Vigilance, Edwards Lifesciences, Irvine, CA, USA) was used to measure cardiac output automatically. The system provides average measurements over 3- to 6-min period with continuously updated (about every 60 sec), time-averaged, cardiac output values. Evaluations of cardiac output using both CCO and BCO measurements were performed at stable conditions after induction of anesthesia and also after weaning from cardiopulmonary bypass in each patient. As BCO measurement, 10 ml of ice-cold 5% glucose solution (BCO-IC) or room-temperature 5% glucose solution (BCO-RT) were injected randomly over the respiratory cycle within 2–3 sec using a closed-injectate delivery system (CO-Set plus, Edwards Lifesciences, Irvine, CA USA) with in-line temperature measurement. Thermodilution curves were always plotted to detect artifacts. Each time, two BCO-IC and two BCO-RT measurements were performed, and the averaged value was taken as the paired BCO-IC and BCO-RT values. The paired CCO value was obtained by averaging CCO values just before and after the BCO measurement.

All results are expressed as mean ± standard deviation (SD). Linear regression was performed. To compare CCO and BCO measurements, bias (the mean difference between the two methods) was calculated to evaluate the systematic error between two methods[13]. Precision (the SD of the bias) is representative of the random error or variability between the different techniques. The relationship between the two techniques was analyzed by linear regression and the agreement according to Bland and Altman[13]. Statistical analysis was performed using software Statview 5.0 (SAS Institute Inc. Cary, NC, USA) for Macintosh. Statistical significance was considered as $P<0.05$.

Results

Twenty-one patients undergoing coronary arterial bypass surgery (n=13), valve surgery (n=3), both valve and coronary arterial bypass surgery (n=4) and valve and closure of the foramen ovale surgery (n=1) were included. The mean age was 64 years (range, 39 to 77 years), mean height was 160 cm (range, 146 to 180 cm) and mean body weight was 61 kg (range, 42 to 89 kg). The CO measurements were obtained twice in each patient, but one measurement after anesthesia induction in a foramen ovale patient was excluded due to the existence of intracardiac shunt, and thus total 41 CO data sets (each data had CCO, BCO-RT, and BCO-IC) were analyzed.

The mean temperature was 23.6±2.4℃ for RT injectate, and 11.0±1.5℃ for IC injectate. The average pulmonary arterial blood temperature was 36.7±0.6℃. BCO-IC ranged from 2.2 to 9.7 L/min, BCO-RT from 2.1 to 9.9 L/min, and CCO from 2.3 to 12.4 L/min. Linear regression analysis revealed good correlation between CCO and BCO-RT (r=0.962), CCO and BCO-IC (r=0.962), and BCO-RT and BCO-IC (r=0.986) (**Fig. 1**). The analysis according to Bland and Altman showed a good agreement (**Fig. 2**) between the mean bias of BCO-IC and

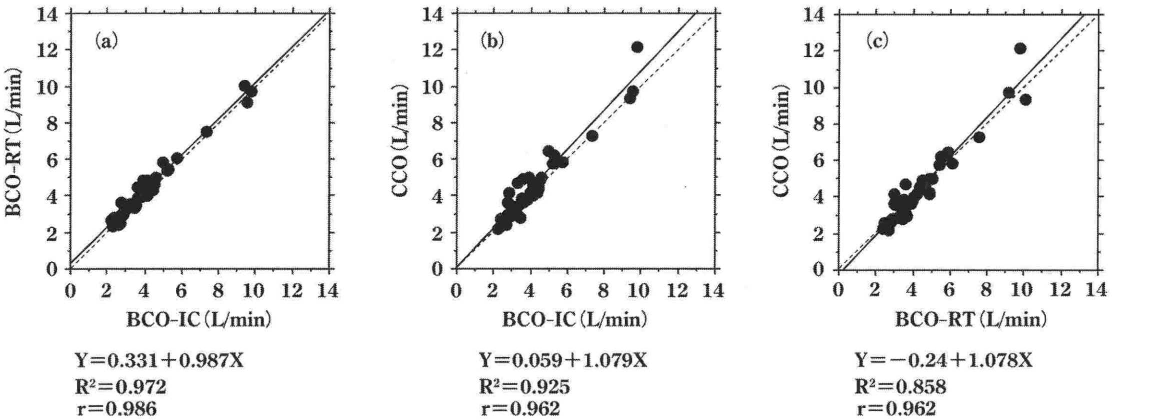

Figure 1

Linear regression analysis between BCO-RT and BCO-IC (r=0.986) (**a**), CCO and BCO-IC (r=0.962) (**b**), and CCO and BCO-RT (r=0.962) (**c**).
CCO; Continuous cardiac output, BCO-RT; Bolus cardiac output using room temperature injectate, BCO-IC; Bolus cardiac output using ice-cold injectate.

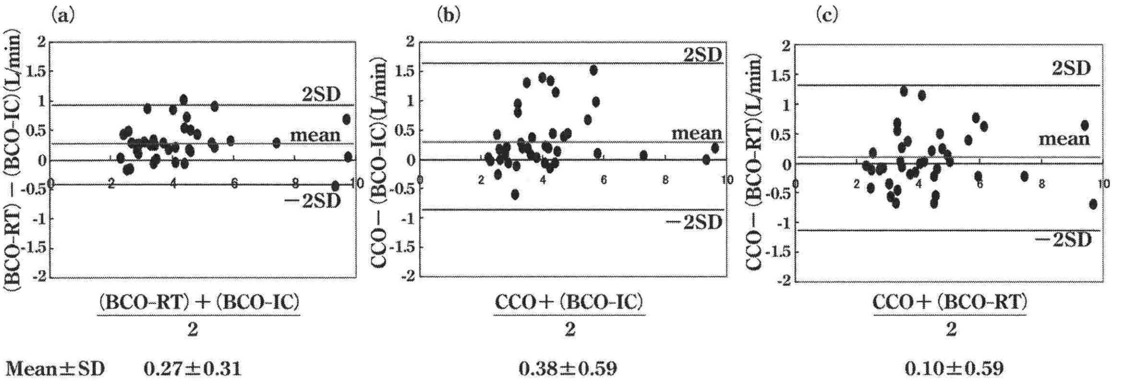

Figure 2

Bland and Altman plots for comparisons between the mean bias of BCO-IC and BCO-RT (mean bias 0.27 L/min) (**a**), between CCO and BCO-IC (mean bias 0.38 L/min) (**b**), and between CCO and BCO-RT (mean bias 0.10 L/min) (**c**).
CCO; Continuous cardiac output, BCO-RT; Bolus cardiac output using room temperature injectate, BCO-IC; Bolus cardiac output using ice-cold injectate.

BCO-RT (mean bias 0.27 L/min), between BCO-IC and CCO (mean bias 0.38 L/min), and between BCO-RT and CCO (mean bias 0.10 L/min). On the other hand, precision (the SD of the bias) of difference between BCO-IC and BCO-RT (0.31 L/min) was smaller than that between BCO-IC and CCO (0.59 L/min), and than that between BCO-RT and CCO (0.59 L/min).

Discussion

Since CCO with a thermodilution technique was first introduced and applied clinically at 1990s, the CCO method has been widely used in the operating room and the critical care unit for continuous monitoring of cardiac output due to its simplicity and feasibility despite of its rather high cost[14]. In the CCO method, a safe level of heat is transferred to the blood by a computer-controlled thermal filament mounted on a pulmonary artery catheter [14]. The pseudo random input (heating signal power) and output (change of the blood temperature) sequence analyses allow the subtraction of thermal noise (respiration effects, drug infusions, slower long term temperature changes) from the desired temperature signal[14].

CCO has several advantages over BCO, such as the continuity in measurement, no need of injectate and low risk of infection. CCO is especially superior to BCO in case of rapid changes of cardiac output as often observed in cardiac surgical patients, when BCO can not follow the changes on time.

Many efforts have been made to evaluate the accuracy of CCO, but the results are not consistent among the clinical studies, ranging from excellent[8～10,15], acceptable agreement[11], to no agreement[12]. Bottinger et al.[8] and Sun et al.[15] reported high correlations between CCO and BCO in cardiac surgical patients and septic shock patients, respectively, whereas Zollner et al.[12] reported a discrepancy between BCO and CCO above the clinically acceptable limits in cardiac surgical patients. Our results showed a good correlation between CCO and BCO, which are consistent with Bottinger et al.[8] and Sun et al.[15] and others[9,10]. However, precisions (standard deviation of differences) between [BCO-IC－CCO] (0.59 L/min) and [BCO-RT－CCO] (0.59 L/min) in this study were larger than a limit of acceptability (0.50 L/min). Therefore, in some clinical situation, BCO is still necessary for accurate evaluation of cardiac output.

As for comparison between cold versus room temperature solutions for BCO measurement, a room temperature solution is easier to administer, and there is no waiting time for cooling, no special ice containers, no periodic ice replacement to maintain a low temperature and little concern for possible solution warming during injection[6]. Therefore, a room temperature solution is better as the injectate for BCO than a cold solution, if the accuracy of BCO-RT is equivalent with BCO-IC. In this study, the analysis according to Bland and Altman showed an excellent agreement between the mean biases of BCO-IC and BCO-RT (mean bias 0.27 L/min), indicating the equivalent accuracy between cold and room temperature solutions for BCO measurement. It should be also concerned that cold bolus injection causes cooling of the SA node, resulting to decrease the heart rate and thus the cardiac output[16,17]. From the point of this effect, the BCO-RT may possibly be more accurate than with BCO-IC because room temperature solution is more physiological than cold solution.

According to the present study, it is concluded that room temperature injectate instead of cold injectate is preferable in cardiac surgical patients for assessment of cardiac output, which is equivalent in accuracy and more convenient as well as less expensive.

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