Cardiothoracic Anesthesia, Respiration and Airway

Cardiac output by PulseCO™ is not interchangeable with thermodilution in patients undergoing OPCAB

[L'évaluation du débit cardiaque par PulseCO™ n'est pas interchangeable avec celle de la thermodilution chez des patients devant subir un PACCB]

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Purpose: To investigate the reliability of cardiac output assessed by arterial pressure waveform (PulseCO™) in comparison with bolus thermodilution measurements in patients undergoing off-pump coronary artery bypass grafting (OPCAB).

Methods: 23 patients who underwent OPCAB were enrolled in this study. After premedication with oral diazepam 10 mg, anesthesia was induced with midazolam, fentanyl and vecuronium. After induction, radial artery and pulmonary artery catheters were inserted. Cardiac output was measured simultaneously by the PulseCO™ and the bolus thermodilution method using the Vigilance™ monitor: 1) after sternotomy, 2) after opening the mediastinum, and 3) at the end of surgery. The PulseCO™ was calibrated initially with cardiac output determined by the thermodilution method after induction of anesthesia.

Results: The correlation coefficients between the two techniques at the three measurement periods were: 1) $R^2 = 0.49$, 2) $R^2 = 0.52$, 3) $R^2 = 0.55$. The limits of agreement (bias ± 2 SD of bias) were: 1) 0.71 ± 2.66, 2) 0.30 ± 1.97, 3) 0.76 ± 3.85 $L \cdot min^{-1}$.

Conclusions: Cardiac output by PulseCO™ is not interchangeable with cardiac output measured by thermodilution in patients undergoing OPCAB.

Objectif : *Vérifier la fiabilité de l'évaluation du débit cardiaque par ondes de tension artérielle (PulseCO™) comparées à la thermodilution de bolus chez des patients devant subir un pontage aortocoronarien à cœur battant (PACCB).*

Méthode : *L'étude a porté sur 23 patients devant subir un PACCB. Une prémédication orale de 10 mg de diazépam a été administrée, puis l'anesthésie a été induite avec du midazolam, du fentanyl et du vécuronium. Après l'induction, des cathéters ont été insérés dans les artères radiale et pulmonaire. Le débit cardiaque a été mesuré simultanément par PulseCO™ et par la méthode de thermodilution de bolus en utilisant le moniteur Vigilance™ : 1) après la sternotomie 2) après l'ouverture du médiastin et 3) à la fin de l'opération. Le PulseCO™ a été calibré au départ avec le débit cardiaque mesuré par la thermodilution après l'induction de l'anesthésie.*

Résultats : *Les coefficients de corrélation entre les deux techniques et à trois périodes de mesures différentes ont été : 1) $R^2 = 0,49$ 2) $R^2 = 0,52$ 3) $R^2 = 0,55$. Les limites de concordance (biais ± 2 écarts types de biais) ont été : 1) 0,71 ± 2,66, 2) 0,30 ± 1,97, 3) 0,76 ± 3,85 $L \cdot min^{-1}$.*

Conclusion : *La mesure du débit cardiaque avec le PulseCO™ n'est pas interchangeable avec la mesure réalisée par thermodilution chez des patients devant subir un PACCB.*

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DURING cardiac surgery, especially off-pump coronary artery bypass grafting (OPCAB), heart rate and arterial blood pressure change dynamically and sometimes dramatically. Under these conditions, a beat-by-beat cardiac output (CO) measurement is useful to understand hemodynamics.

The thermodilution technique of determining CO using a pulmonary artery catheter is standard.[1] However, the thermodilution technique requires several stable cardiac beats to calculate CO from the temperature time curve. In contrast, the PulseCO™ (Lidco Ltd., London, UK) calculates CO from the arterial pressure waveform of a peripheral artery such as the radial artery using autocorrelation by nonlinear transformation of the input analogue arterial pressure.[2] Therefore, the PulseCO™ can determine beat-by-beat CO. However, the arterial pressure waveform often changes during surgery because the arterial compliance changes according to sympathetic activity, intravascular blood volume, position, etc.[3–5] These factors may induce miscalculation of the CO by PulseCO™ because of inaccurate estimation of pulse wave velocity.[2] The purpose of the present study was to determine whether CO measured by the PulseCO™ is interchangeable with CO measured by the bolus thermodilution method with the Vigilance™ monitor (Edwards Lifesciences LLC, Irvine, CA, USA) in patients undergoing OPCAB.

Methods

Twenty-three patients scheduled to undergo OPCAB were enrolled in this study after obtaining informed consent to the institutionally approved protocol. Patients who suffered from aortic valve stenosis and regurgitation were excluded from the study. After premedication with oral diazepam 10 mg, anesthesia was induced with midazolam 0.15 $mg \cdot kg^{-1}$ *iv* and fentanyl 10 $\mu g \cdot kg^{-1}$ *iv*. Endotracheal intubation was facilitated with vecuronium 0.15 $mg \cdot kg^{-1}$ *iv*. Anesthesia was maintained with midazolam, fentanyl and vecuronium. After induction, radial artery and pulmonary artery catheters (Edwards Lifescience LLC, Irvine, CA, USA) with a 9 Fr introducer (Percutaneous Sheath Introducer Kit, Arrow International, Bernville, PA, USA) were inserted. CO was measured after induction to calibrate the PulseCO™ and, subsequently, after sternotomy, after opening the mediastinum and at the end of surgery. No vasopressor or vasodilator drugs were used until coronary artery bypass grafting was initiated. CO by the standard thermodilution method was measured using the Vigilance™ system. Other variables were measured by standard monitors (Life Scope 9™, Nihon Kohden, Tokyo, Japan). The PulseCO™ was connected to the patient monitor and analyzed the arterial pressure waveform to calculate CO. The PulseCO™ was initially calibrated with the value of CO measured by thermodilution, and no recalibration was performed during the study. For the thermodilution method, CO was measured three times by injection of 0.2 $mL \cdot kg^{-1}$ saline of less than 5°C and the mean value was calculated.

Statistical analysis

Data are expressed as mean ± standard deviation (SD). Hemodynamic variables were analyzed by repeated measures analysis of variance with Bonferroni correction. Correlation between CO measured by the PulseCO™ and thermodilution was determined by linear regression analysis. The Blant-Altman plot was used to compare the bias (the mean of the differences) and limits of agreement (bias ± 2 SD of bias) between the two methods.[6] *A priori*, a difference within the range of ± 0.5 $L \cdot min^{-1}$ was considered clinically acceptable to support the conclusion that the two methods are interchangeable. A P-value < 0.05 was considered statistically significant.

Results

Fourteen males and nine females with a mean age of 68 ± 9 yr were controlled. Mean height and weight were 159 ± 9 cm and 61 ± 11 kg, respectively. Hemodynamic data are presented in Table I. Heart

TABLE I Changes of cardiac output and hemodynamic variables measured by the pulmonary artery catheter

	Control (calibration)	*After sternotomy*	*After opening the mediastinum*	*At the end of surgery*
Heart ratem (min^{-1})	57 ± 8	66 ± 16*	72 ± 12*	86 ± 14*
Mean arterial pressure (mmHg)	75 ± 12	74 ± 15	67 ± 12*	72 ± 12
Mean pulmonary artery pressure (mmHg)	16 ± 5	15 ± 4	14 ± 4	17 ± 4
Central venous pressure (mmHg)	7 ± 4	8 ± 4	6 ± 4	7 ± 3
Pulmonary vascular resistance ($dyne \cdot sec^{-1} \cdot min^{-5}$)	1816 ± 820	1791 ± 631	1522 ± 598*	1250 ± 480*
Pumonary vascular resistance ($dyne \cdot sec^{-1} \cdot min^{-5}$)	374 ± 185	367 ± 139	293 ± 94*	286 ± 103*

Data are expressed as mean ± standard deviation; *$P < 0.05$ *vs* control (calibration).

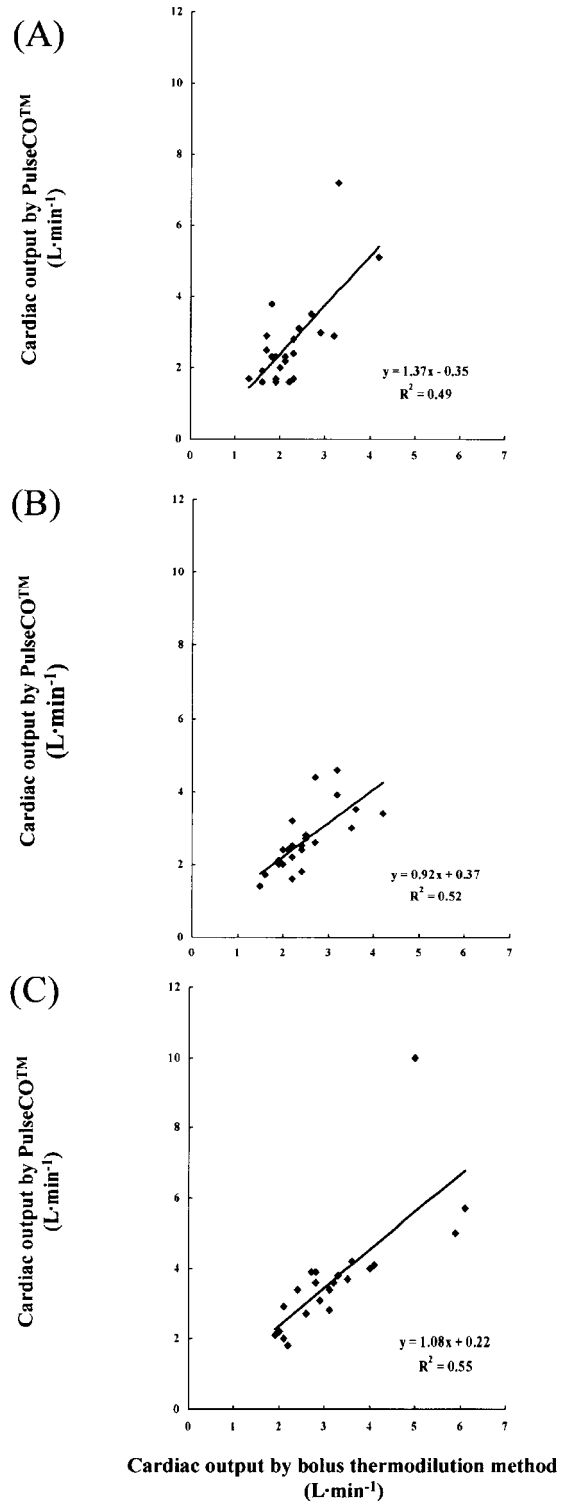

FIGURE 1 Scatter plot of individual cardiac output measurements by both the PulseCO™ and the bolus thermodilution method: A) after sternotomy; B) after opening the mediastinum; C) at the end of surgery. The solid lines are linear regression lines.

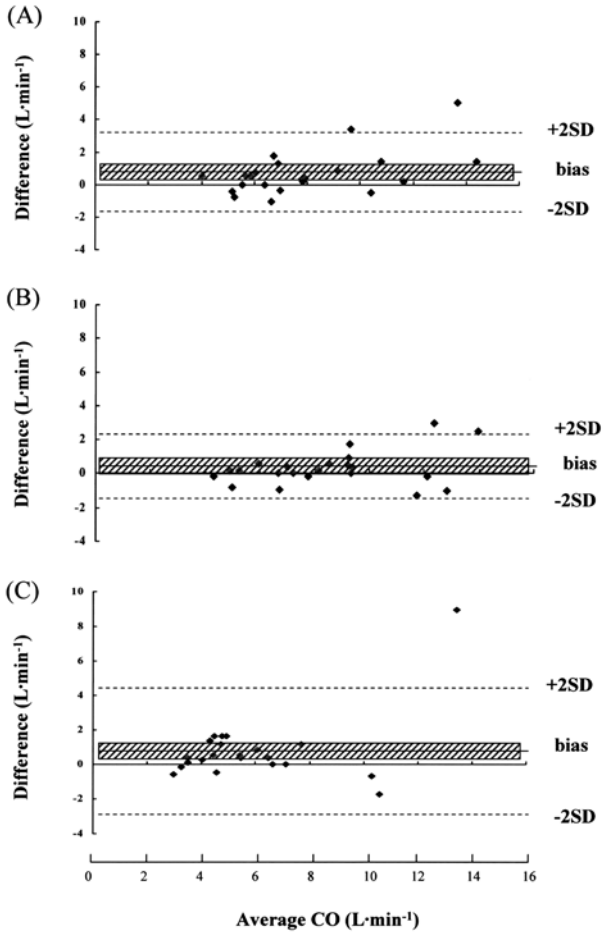

FIGURE 2 Bland-Altman plot of cardiac output measurements from PulseCO™ and bolus thermodilution method: A) after sternotomy; B) after opening the mediastinum; C) at the end of surgery. Average cardiac output was defined as (cardiac output by PulseCO™ + cardiac output by thebolus thermodilution method) ÷ 2. The solid lines indicate bias (the mean of the differences). The dashed lines indicate the limits of agreement (bias ± 2 SD of bias). The shaded area represents the difference chosen to be acceptable while still supporting the conclusion that the two methods are interchangeable (0.5 L–min^{-1} above and below the mean difference).

rate increased after sternotomy, after opening the mediastinum and at the end of surgery ($P < 0.05$). Mean arterial pressure decreased ($P < 0.05$) after opening the mediastinum. Systemic and pulmonary vascular resistance were also lower ($P < 0.05$) after opening the mediastinum and at the end of surgery compared to control values. The correlation coefficients (R^2) were relatively low between COs measured

TABLE II Mean difference (bias) between cardiac output by the PulseCO™ and cardiac output by thermodilution, lower limits of agreement (bias -2 SD) and upper limits of agreement (bias +2 SD)

	Bias	*Lower limits of agreement*	*Upper limits of agreement*
After sternotomy	0.71 (0.13 ~ 1.29)	-1.94 (-2.94 ~ 0.95)	3.37 (2.38 ~ 4.37)
After opening the mediastinum	0.30 (-0.13 ~ 0.73)	-1.67 (-2.41 ~ 0.93)	2.27 (1.53 ~ 3.01)
At the end of surgery	0.76 (-0.07 ~ 1.60)	-3.09 (-4.53 ~ -1.65)	4.62 (3.18 ~ 6.07)

Values in parentheses represent 95% confidence interval.

by the PulseCO™ and thermodilution (Figure 1). The bias was positive at every measurement (Table II, Figure 2). The limits of agreement exceeded the predetermined limits judged to be clinically acceptable.

Discussion

The main result from this study was the observation that PulseCO™ may overestimate CO in patients undergoing OPCAB, when compared to CO measured by thermodilution.

The method to determine CO from characteristics of the arterial pressure waveform is called the 'pulse contour method'.[3] Pulse contour methods use properties of the aorta and arterial system to determine an aortic flow from an arterial pressure waveform. However, aortic pathology and variations in the aortic sectional area present challenges in calibrating arterial pressure waveform in individual patients. Therefore, pulse contour methods require calibration by another method.[2] Originally a lithium chroride indicator dilution technique was used to calibrate the PulseCO™ measurement.[7,8] However, in the present study, the PulseCO™ was calibrated with CO measured by the bolus thermodilution method using a pulmonary artery catheter, because a lithium chroride indicator was not available for this purpose in Japan and the bolus thermodilution method is the current standard to measure CO.[1] In the present study, CO measured after induction was the same between the two methods.

The PulseCO™ has previously been reported to be a useful CO monitor after cardiac surgery.[9] However, in the present study, correlation coefficients between CO measured by the PulseCO™ and thermodilution were smaller, moreover, and bias was relatively larger than documents in previous studies.[2,10] The observed bias from 0.30 to 0.76 $L \cdot min^{-1}$ and limits of agreement exceeding ± 0.5 $L \cdot min^{-1}$ suggest that the PulseCO™ overestimates CO measured by thermodilution in patients undergoing OPCAB.

The PulseCO™ algorithm uses aortic flow velocity to calculate CO from the mean arterial pressure.[2] However, velocity may change by alteration of cardiac and/or arterial compliance, even when mean arterial pressure remains the same. In cardiac surgery, cardiac compliance changes markedly due to the alteration of intrathoracic pressure by sternotomy and opening the mediastinum. In addition, arterial compliance may be altered by vasoactive drugs (e.g., phenylephrine, dopamine, nitroglycerine) or body temperature. However, the PulseCO™ cannot continuously measure the arterial compliance. Therefore, the PulseCO™ has the potential to miscalculate CO due to 'drift' and may need several calibrations to measure CO during surgery. In our study, we calibrated the PulseCO™ only once, reflecting how it is generally used in the clinical setting.

We conclude that CO measurement by PulseCO™ is not interchangeable with CO measured by thermodilution in patients undergoing OPCAB.

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