Comparison of Uncalibrated Arterial Pressure Waveform Analysis with Continuous Thermodilution Cardiac Output Measurements in Patients Undergoing Elective Off-Pump Coronary Artery Bypass Surgery

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Objective: **Monitoring of cardiac output is required during anesthesia for off-pump coronary artery bypass (OPCAB) surgery. Recently, FloTrac, a new device for arterial pressure waveform analysis for cardiac output (APCO) monitoring without external calibration, was developed. The authors have compared APCO with STAT-mode continuous cardiac output (SCCO) in patients undergoing OPCAB surgery.**

Design: **A clinical study.**

Setting: **A university hospital (single institution).**

Participants: **Thirty consecutive patients undergoing elective OPCAB surgery.**

Interventions: **Arterial pressure measurement with FloTrac, pulmonary arterial catheter insertion.**

Measurements and Main Results: **APCO and SCCO measurements were recorded after pulmonary artery catheter insertion (T1), after sternotomy (T2), after heart positioning for left anterior descending artery anastomosis (T3, T4), after heart positioning for obtuse marginal artery anastomosis (T5, T6), after heart positioning for posterior descending artery anastomosis (T7, T8), and after sternal closure (T9). APCO and SCCO were compared using the Bland-Altman method and the percentage error by Critchley's criteria. SCCO and APCO ranged from 2.1 to 6.9 L/min and 1.2 to 7.4 L/min, respectively, and showed low correlation (r = 0.29). The overall bias by the Bland-Altman method between SCCO and APCO was −0.23 L/min, with a precision of −1.4 to 0.9 L/min, and the overall limits of agreement were −2.5 to 2.0 L/min. The overall mean CO was 4.0 ± 0.95 L/min. The overall percentage error between SCCO and APCO measurements was 57%.**

Conclusions: **Uncalibrated APCO values do not agree with thermodilution SCCO and significantly overestimated the SCCO in patients undergoing OPCAB surgery. Further evaluation is required to verify the clinical acceptance of FloTrac APCO in OPCAB surgery.**

KEY WORDS: cardiovascular, arterial pressure measurement, measurement techniques, cardiac output, FloTrac, OPCAB

CARDIAC OUTPUT (CO) IS AN IMPORTANT PARAMETER during the monitoring of critically ill patients. The current clinical standard for measuring CO is the thermodilution technique with a pulmonary artery catheter. This method, however, has drawbacks due to its invasiveness, and questions have arisen regarding its risk-benefit ratio. Less invasive techniques, including PiCCO (Pulsion Medical System, Munich, Germany) and LiDCO (LiDCO Ltd, London, UK), have been utilized, but the requirement for calibration has limited their usefulness.

Recently, a new device, FloTrac/Vigileo (Edwards Lifesciences, Irvine, CA), was developed for arterial pressure waveform-based CO (APCO) estimation. This device is safe and simple, requiring only a peripheral arterial catheter. Unlike the PiCCO and LiDCO devices, the FloTrac/Vigileo device does not require calibration for the measurement of cardiac output. To date, however, clinical studies evaluating the performance of FloTrac/Vigileo have reported variable results,[1-5] although most of these studies were performed in postoperative patients or those undergoing cardiac surgery with cardiopulmonary bypass (CPB).

Off-pump coronary artery bypass surgery (OPCAB) involves lifting, rotating, and compressing the beating heart. These maneuvers may result in acute deterioration of hemodynamics that must be dealt with by anesthesiologists. Since intermittent thermodilution CO may be time-consuming and may result in sporadic values, and CCO values have an inherent 5- to 15-minute delay in responding to abrupt changes in cardiac output, many clinicians prefer STAT-mode continuous cardiac output (SCCO). Excellent correlation, accuracy, and precision have been observed between thermodilution CO and SCCO.[6,7] The authors have, therefore, compared APCO with SCCO in patients undergoing OPCAB surgery.

METHODS

This study was approved by the Institutional Review Board, and written informed consent was obtained from each patient. Thirty consecutive patients undergoing elective OPCAB surgery were prospectively enrolled. Patients with cardiac arrhythmia, intracardiac shunt, valvular heart disease, or symptomatic peripheral vascular disease were excluded. All patients were treated with individual cardiac medication until the morning of surgery, and premedicated with 7.5 mg of oral midazolam 1 hour before transfer to the operating room.

Upon arrival, each patient received routine monitoring, including a 5-lead electrocardiogram, pulse oximetry, and radial artery catheterization (20-G, Angiocath Plus; Becton Dickinson Korea, Gumi-si, Korea). The radial artery catheter was connected to a FloTrac pressure transducer. Vigileo (ver 1.10) then was loaded with the patient's demographic data, and pressure zeroing was performed. APCO is calculated by the Vigileo as CO = heart rate × stroke volume (SV = χ × pulsatility). The rate of adjustment of χ, a constant quantifying arterial compliance and vascular resistance, was 1 minute.

After preoxygenation, anesthesia was induced with 0.2 mg/kg of etomidate and 1 mg/kg of rocuronium, and maintained with target-controlled infusion (TCI) of 1 to 1.5 μg/mL of propofol and 10-15 ng/mL of remifentanil. After endotracheal intubation, a 9F central venous catheter with an integral valve (MAC; Arrow International Inc,

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Table 1. Demographic Data

Variables	Values (n = 28)
Sex (M/F)	26/2
Age (y)	60.5 ± 8.0
Height (cm)	166.4 ± 6.5
Weight (kg)	67.4 ± 8.7
Ejection fraction (%)	55.8 ± 11.2

NOTE. Values are mean ± SD.

Reading, PA) was inserted into the right internal jugular vein. A 7.5F pulmonary artery catheter (CCOmbo/REF, 774HF75; Edwards Lifesciences) was introduced and connected to the Vigilance monitor (Edwards Lifesciences). The Vigilance monitor was set in the STAT-mode, which displayed the actual CO values within the past 60 seconds. The position of the catheter was confirmed by pressure curves and by immediate intraoperative chest radiograph. A Medtronic suction heart positioner and stabilization system (Octopus, Medtronic Inc, Minneapolis, MN) were used to perform the graft anastomosis of the coronary arteries. During compression of the heart, the mean arterial pressure was maintained close to baseline values by phenylephrine injection, dopamine infusion, placement of the patient in the Trendelenburg position, and fluid administration. Normothermia was maintained with a Hotline system (SIMS Inc, Rockland, MD), increased ambient operating room temperature (25°C) and a warmed water mattress (38°C).

APCO, SCCO, and stroke volume (SV) measurements were recorded 10 minutes after pulmonary artery catheter insertion (T1), 10 minutes after sternotomy (T2), 5 minutes (T3), and 10 minutes (T4) after heart positioning for anastomosis of the left internal mammary artery (LIMA) and left anterior descending artery (LAD), 5 minutes (T5) and 10 minutes (T6) after heart positioning for obtuse marginal artery (OM) anastomosis, 5 minutes (T7) and 10 minutes (T8) after heart positioning for posterior descending artery (PDA) anastomosis, and 5 minutes after sternal closure (T9). Because APCO values are calculated and updated at 20-second intervals, an average of 3 consecutive measurements of APCO at each time point was determined. Other hemodynamic measurements, including heart rate (HR), systolic (SAP) and mean arterial pressure (MAP), central venous pressure (CVP), mean pulmonary arterial pressure (MPAP), and mixed venous oxygen saturation (SvO_2), were recorded at each time point. All data were collected by trained observers who did not participate in patient care.

APCO and SCCO were compared using the Bland-Altman method.[8] Bias was defined as the mean difference between APCO and SCCO values. The limits of agreement were calculated as bias ± 2 × SD. The percentage error was calculated as the ratio of 2 SD of the bias to mean CO and, according to Critchley's criteria, was considered clinically acceptable if below 30%.[9] Linear regression analysis was used to determine correlation between continuous parameters. Hemodynamic changes in time were compared using one-way analysis of variance for repeated measurements. Statistical analysis was performed using SigmaStat (ver 3.1; SPSS Inc, Chicago, IL). A p value <0.05 was considered statistically significant. All data are presented as mean ± SD.

RESULTS

Of the 30 patients, 2 were excluded because of CPB conversion during LAD anastomosis. From the enrolled 28 patients, 234 CO pairs were analyzed. PDA anastomosis was not performed in 7 patients, and OM and LAD anastomoses were not performed in 1 patient. Demographic data of the patients are shown in Table 1. Hemodynamic variables during CO determination are summarized in Table 2. Analyses of CO data for every measurement point, including correlation, bias, limits of agreement, and percentage error, are shown in Table 3. SCCO and APCO ranged from 2.1 to 6.9 L/min and 1.2 to 7.4 L/min, respectively, with mean (SD) values of 3.9 L/min (0.8) and 4.1 L/min (1.1), respectively. SCCO and APCO showed low correlation (Fig 1).

Using the Bland-Altman method, the authors found that the overall bias between SCCO and APCO was −0.23 L/min, with a precision of −1.4 to 0.9 L/min, and the overall limits of agreement were −2.5 to 2.0 L/min (Fig 2). The overall mean CO was 4.0 ± 0.95 L/min. The overall percentage error between SCCO and APCO measurements was 57%. Paired t test showed that SCCO and APCO differed significantly (p = 0.002).

Table 2. Changes in Hemodynamic Variables

	T1	T2	T3	T4	T5	T6	T7	T8	T9
HR (beats/min)	56 ± 9	58 ± 9	66 ± 12*	65 ± 12*	68 ± 14*	69 ± 14*	69 ± 13*	70 ± 13*	74 ± 15*
SAP (mmHg)	111 ± 17	126 ± 17*	114 ± 15	112 ± 14	105 ± 11	106 ± 10	104 ± 12	106 ± 15	111 ± 11
MAP (mmHg)	73 ± 12	85 ± 11*	76 ± 12	75 ± 9	74 ± 7	74 ± 5	72 ± 8	74 ± 9	75 ± 7
PP (mmHg)	54 ± 14	61 ± 17*	52 ± 10	51 ± 11	42 ± 9*	44 ± 9*	43 ± 8*	46 ± 12	52 ± 9
MPAP (mmHg)	14 ± 3	17 ± 6	18 ± 4*	18 ± 6*	22 ± 6*	23 ± 6*	22 ± 6*	22 ± 7*	16 ± 4
CVP (mmHg)	7 ± 2.7	8 ± 3	10 ± 3.5*	10 ± 3.4*	15 ± 4.7*	15 ± 5.2*	15 ± 4.8*	15 ± 5.3*	8 ± 3.3
SvO_2 (%)	84 ± 5	84 ± 6	82 ± 6	82 ± 7	76 ± 10*	76 ± 10*	79 ± 8*	79± 7*	80 ± 8
SVp (mL/beat)	70 ± 17	61 ± 15*	66 ± 17	66 ± 13	57 ± 14*	54 ± 13*	59 ± 16*	56 ± 15*	61 ± 17*
SVa (mL/beat)	71 ± 16	75 ± 22	65 ± 13	64 ± 12	54 ± 16*	57 ± 14*	61 ± 14*	61 ± 16*	59 ± 15*

NOTE. Values are mean ± SD.

Abbreviations: HR, heart rate; SAP, systolic arterial pressure; MAP, mean arterial pressure; PP, pulse pressure; MPAP, mean pulmonary arterial pressure; CVP, central venous pressure; SvO_2, mixed venous O_2 saturation; SVp, stroke volume derived from pulmonary artery catheter; SVa, stroke volume derived from arterial catheter; T1, 10 min after pulmonary artery catheter insertion; T2, 10 min after sternotomy; T3, during left anterior descending artery (LAD) anastomosis at 5 min; T4, during LAD anastomosis at 10 min; T5, 5 min after a heart position for obtuse marginal artery (OM) anastomosis; T6, 10 min after a heart position for OM anastomosis; T7, 5 min after a heart position for posterior descending artery (PDA) anastomosis; T8, 10 min after a heart position for PDA anastomosis; T9, after 5 min after sternal closure.

NOTE. Values are mean ± SD.

*$p < 0.05$ v T1.