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Research Article

The Difference between Arterial Pressure Waveform Cardiac Output Versus Thermo dilution Cardiac Output as a Perioperative Dynamic Evaluation of the Severity of Aortic Insufficiency

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Abstract

Objective: To determine whether the degree of overestimation of an arterial pressure-based cardiac output (APCO) (Vigileo-FloTrac system, Edwards Life science, Irvine, CA) with respect to a thermo dilution cardiac output (CCO) can be the parameter in perioperative dynamic evaluation of the severity of aortic insufficiency (AI)

Methods: APCO and CCO were measured together with simultaneous transesophageal echocardiographic parameters of the vena contract a width (VC) in the 2-dimensional mid-esophageal long-axis view and the pressure half-time (PHT) in the deep transgastric long axis view.

Results: In control group, Bland-Altman between CCO and APCO showed a bias of -0.03343 L/min (95% limits of agreement: -1.409 to 1.342 L/min). In mild AI group, the bias was 0.7044 L/min (95% limits of agreement: -0.3481 to 1.757 L/min). In moderate AI group, the bias was 1.669 L/min (95% limits of agreement: 0.1367 to 3.200 L/min). In severe AI group the bias was 2.449 L/min (95% limits of agreement: 1.010 to 3.887 L/min). The APCO-CCO difference showed a strong correlation with VC ($r = 0.8536$, $p < 0.0001$; VC = 2.634*APCO-CCO difference + 0.4156) and PHT ($r = -0.8212$, $p < 0.0001$; PHT = -190.2*APCO-CCO difference + 680.4).

Conclusion: The strong correlation was observed between the degree of APCO-CCO difference and the degree of AI measured with TEE-derived VC and PHT. Therefore, in perioperative patients with AI, the degree of overestimation of APCO compare to CCO is related with the severity of AI.

Keywords: *Cardiac output; Aortic insufficiency; Arterial pulse; Waveform; Arterial pressure; Thermo dilution; Echocardiography; Perioperative; Monitoring*

Abbreviations: APCO: Arterial pressure-based cardiac output; CCO: Continuous thermo dilution cardiac output; AI: Aortic insufficiency; VC: Vena contracta; PHT: Pressure half-time.

Introduction

Cardiac output is crucial as part of dynamic parameter for perioperative goal directed therapy and hemodynamic optimization. The accuracy of the goal standard invasive intermittent bolus thermo dilution cardiac output was extensively demonstrated and comparable with the continuous thermo dilution cardiac output (CCO) [1-3]. However, pulmonary artery catheter is needed. A newer minimally invasive cardiac output, arterial pressured-based (APCO), analyze area under the curve of arterial pressure waveform in correlated with the patient demographic data. The APCO was comparable and able to reflect the CCO during high risk and cardiac surgery in patients with normal aortic valve function [4-7].

The quantitative measurements using proximal is velocity surface area (PISA) method has been shown to provide accurate quantization of aortic insufficiency (AI) [8]. However, the quantitative measurements are time-consuming and inconvenience to be used as a real-time dynamic parameter for intra-operative clinical management. On the other hand, the semi quantitative methods appear specific but poorly sensitive, except for vena contracta, which provides good discriminative value [9]. Patients with AI manifest with elevated peak systolic velocity followed by an abruptly decline generated higher pulse pressure results in higher APCO values compare to CCO [10]. Therefore, we hypothesized that calculating the difference between APCO and CCO might also be useful in dynamic evaluation of the degree of regurgitation. To test this hypothesis, degree of overestimation of APCO compare to CCO was related to simultaneous semi quantitative assessments of severity of AI assessed by transesophageal echocardiography (TEE).

Materials and Methods

The study was approved by the institutional ethical committee, and written informed consent was obtained. Sixty adult patients undergoing elective cardiac surgery were prospectively studied. Exclusion criteria were patients with cardiac rhythm arrhythmias, intracardiac shunts, aortic aneurysm, symptomatic peripheral vascular disease; documented aortic stenosis and intra-aortic balloon pump (IABP), multiple AI jets or eccentric AI jet. Observations were performed in 4 groups of patients depended on preoperative transthoracic echocardiographic documentation: patients without aortic insufficiency (Control group, n = 15), patients with mild aortic insufficiency (Mild AI, n = 15), patients with moderate aortic insufficiency (Moderate AI, n = 15), patients with severe aortic insufficiency (Severe AI, n = 15).

In the operating room, patients received routine monitoring including five-lead electrocardiogram, radial arterial pressure, pulse oximetry, capnography, and blood and rectal temperature monitoring. The radial arterial blood pressure was monitored by using a 20-guage intra-arterial catheter (Leader-Cath; Vygon, Ecouen, France) which was attached through fluid-filled tubing to a pressure transducer sensor. The tubing was pre-checked and re-checked by flushing to make sure there was no air in line or dampening. This pressure transducer sensor (FloTrac system, Edwards Life science, Irvine, CA) has a bifurcated cable which one cable displays continuous blood pressures on the bedside monitor and the other going to the Vigileo monitor (Vigileo, Edwards Life science, Irvine, CA) to analyze for the APCO. For the present study, the software version 3.01 was used. The software algorithm is the analysis of the area under the arterial pressure waveform and the waveform morphology as a proportion to the stroke volume. Pulse rate is calculated by counting the pulse amplitudes. Thus, cardiac output can be displayed continuously from the analyzed stroke volume multiply by pulse rate. Arterial pressure waveform were sampling at a rate of 100 Hz over a 20-second period, which provides 2,000 data points. The APCO values are analyzed and updated at 20-second intervals [11]. Anesthesia was performed with balanced anesthesia according to institutional standards with midazolam, remifentanil, and rocuronium. Transesophageal echocardiography (TEE) (Alokaprosound α10) was placed immediately after intubation. Then, a pulmonary artery catheter (Swan Ganz CCO/VIP; Edwards Life sciences) was placed via an 8.5F introducer into the right internal jugular vein and connected to a monitor (Vigilance II Monitor, Edwards Life sciences) for assessment of the CCO. The CCO value is derived from the calculation of the area under the thermo dilution curve after the small pulse thermal energy emitted by the thermal filament located on the pulmonary artery catheter [12]. To reflect sudden changes in the CCO, the Vigilance II monitor was set in the STAT mode, and every 30 to 60 seconds the displayed CCO is updated, which has been demonstrated to provide accurate measurement of the CCO [13,14]. Then, all pressure transducers were zeroed at the phlebostatic level with the reference landmark of midaxillary line and fourth intercostal space.

During the pre-cardiopulmonary bypass period, the semi quantitative transesophageal echocardiographic measurement of the degree of AI was measured using the vena contracta width (VC) in the 2-dimensional mid-esophageal aortic valve long-axis view and the pressure half-time (PHT) in the deep transgastric long axis view, with electrocardiographic synchronization as summarized in Table 1. APCO and CCO together with TEE and hemodynamic data were recorded simultaneously. All TEE images were recorded on videotape and were analyzed separately by two experienced observers blinded to the clinical and hemodynamic data.

	Mild AI	Moderate AI	Severe AI
Vena contracta width (ME AV LAX)	< 3 mm	3-6 mm	> 6 mm
Pressure half-time (deep TG LAX)	> 500 ms	200-500 ms	< 200 ms

Table 1: *Semi quantitative Measurement of the Severity of AI with TEE.*
Abbreviations: *AI, aortic insufficiency; AV, aortic valve; LAX, long axis; ME, midesophageal; TEE, transesophageal echocardiography; TG, transgastric.*

Statistical analysis was performed using the Sigma Stat 2.03 software package (SPSS, Leuven, Belgium). All data were tested for normal distribution. Differences between patient characteristics and hemodynamic data sets were compared versus control using one-way analysis of variance for repeated measurements, and echocardiographic measurements were compared versus mild AI. Agreements between the CCO and the APCO were assessed with the Bland-Altman analysis [15] by using the Graph Pad software (version Prism 6; Graph Pad Software Inc, San Diego, CA). In each group, all paired APCO and CCO data were related using linear regression analysis and calculation of the Pearson correlation coefficient. The different between APCO and CCO data were also related with simultaneous TEE data using linear regression analysis and calculation of the Pearson correlation coefficient. Data are expressed as mean and standard deviations (SD). Statistical significance was accepted at $p < 0.05$.

Results

Patient characteristics are summarized in Table 2. There was no significant difference among the groups in any of the variables. The hemodynamic data and echocardiographic measurements are summarized in Table 3.

	Control (n = 15)	Mild AI (n = 15)	Moderate AI (n = 15)	Severe AI (n = 15)
Preoperative data				
Sex (male/female)	10/5	9/6	10/5	8/7
Age (y)	57 ± 9	56 ± 8	59 ± 9	59 ± 7
Body mass index (kg/m^2)	25.2 ± 2.6	26.9 ± 2.1	24.8 ± 2.5	24.9 ± 2.7
Ejection fraction (%)	60 ± 14	61 ± 10	61 ± 13	56 ± 11
Diabetes type I (%)	0 (0)	0 (0)	0 (0)	0 (0)
Diabetes type II (%)	4 (27)	3 (20)	4 (27)	4 (27)
COPD (%)	2 (13)	3 (20)	3 (20)	2 (13)
Current medication (%)				
Beta-Blockers	9 (60)	8 (53)	5 (33)	7 (47)
Calcium channel blockers	1 (7)	2 (13)	3 (20)	2 (13)
ACE inhibitors	5 (33)	4 (27)	6 (40)	4 (27)
Nitrates	1 (7)	3 (20)	0 (0)	2 (13)
Diuretics	4 (27)	5 (33)	3 (20)	6 (40)
Acetylsalicylic acid	5 (33)	6 (40)	5 (33)	4 (27)
Oral antidiabetics	4 (27)	2 (13)	2 (13)	4 (27)
Insulin	0 (0)	2 (13)	1 (7)	1 (7)

Table 2: *Patient Characteristics.*

NOTE: *Data are presented as mean ± SD unless noted.*

Abbreviations: *AI, aortic insufficiency; ACE, angiotensin-converting enzyme; COPD, chronic obstructive pulmonary disease. * Different compared with control (P < 0.05).*

	Control (n = 15)	**Mild AI (n = 15)**	**Moderate AI (n = 15)**	**Severe AI (n = 15)**
Heart rate (beats/min)	75 ± 12	68 ± 10	70 ± 12	73 ± 13
Mean arterial pressure (mmHg)	72 ± 7	73 ± 8	71 ± 9	75 ± 9
Mean pulmonary artery pressure (mmHg)	22 ± 2	23 ± 1	19 ± 2*	19 ± 2*
Central venous pressure (mmHg)	13 ± 1	14 ± 1	10 ± 2*	10 ± 2*
CCO (L/min)	4.1 ± 0.6	4.0 ± 0.5	4.0 ± 0.5	3.4 ± 0.4*
APCO (L/min)	4.1 ± 0.7	4.7 ± 0.6*	5.6 ± 0.7*	5.8 ± 0.7*
Vena contracta width (mm)		1.7 ± 0.6	4.2 ± 1.0**	8.3 ± 2.3**
Pressure half-time (ms)		645 ± 88	343 ± 98**	119 ± 34**

Table 3: *Legand: Hemodynamic Data and Echocardiographic Parameters.*

NOTE: *Values are mean ± SD.*

** Significantly different compared with control (P < 0.05).*

*** Significantly different compared with mild AI (P < 0.05).*

Figure 1 displays the Bland-Altman plots and the relationship between the CCO and the APCO in each group. The control group consisted of 15 patients in whom a total of 341 pairs of cardiac output measurements were obtained. In this group, the bias and the 95% limits of agreement were -0.03343 L/min and -1.409 to 1.342 L/min, and a poor correlation was observed (r = 0.3826) between the CCO and the APCO. The mild AI group consisted of 15 patients with 386 pairs of cardiac output measurements. In this group, the bias and the 95% limits of agreement slightly increased to 0.7044 L/min and -0.3481 to 1.757 L/min, and a poor correlation was observed (r = 0.4945) between the CCO and the APCO. The moderate AI group consisted of 15 patients with 372 pairs of cardiac output measurements. In this group, the bias and the 95% limits of agreement increased to 1.669 L/min and 0.1367 to 3.200 L/min, and a poor correlation was observed (r = 0.2483) between the CCO and the APCO. The severe AI group consisted of 15 patients with 316 pairs of cardiac output measurements. In this group, the bias and the 95% limits of agreement increased further to 2.449 L/min and 1.010 to 3.887 L/min, and a poor correlation was also observed (r = 0.2478) between the CCO and the APCO.

Figure 2 demonstrates the linear regression line between the APCO-CCO difference and the simultaneous vena contracta width for all measurements, from mild to severe AI. With the calculation of the Pearson correlation coefficient, a strong correlation was observed (r = 0.8536, p < 0.0001; vena contracta width = 2.634*APCO-CCO difference + 0.4156).

Figure 3 demonstrates the linear regression line between the APCO-CCO difference and the simultaneous pressure half-time for all measurements, from mild to severe AI. With the calculation of the Pearson correlation coefficient, a strong inverse correlation was observed (r = -0.8212, p < 0.0001; pressure half-time = -190.2*APCO-CCO difference + 680.4).

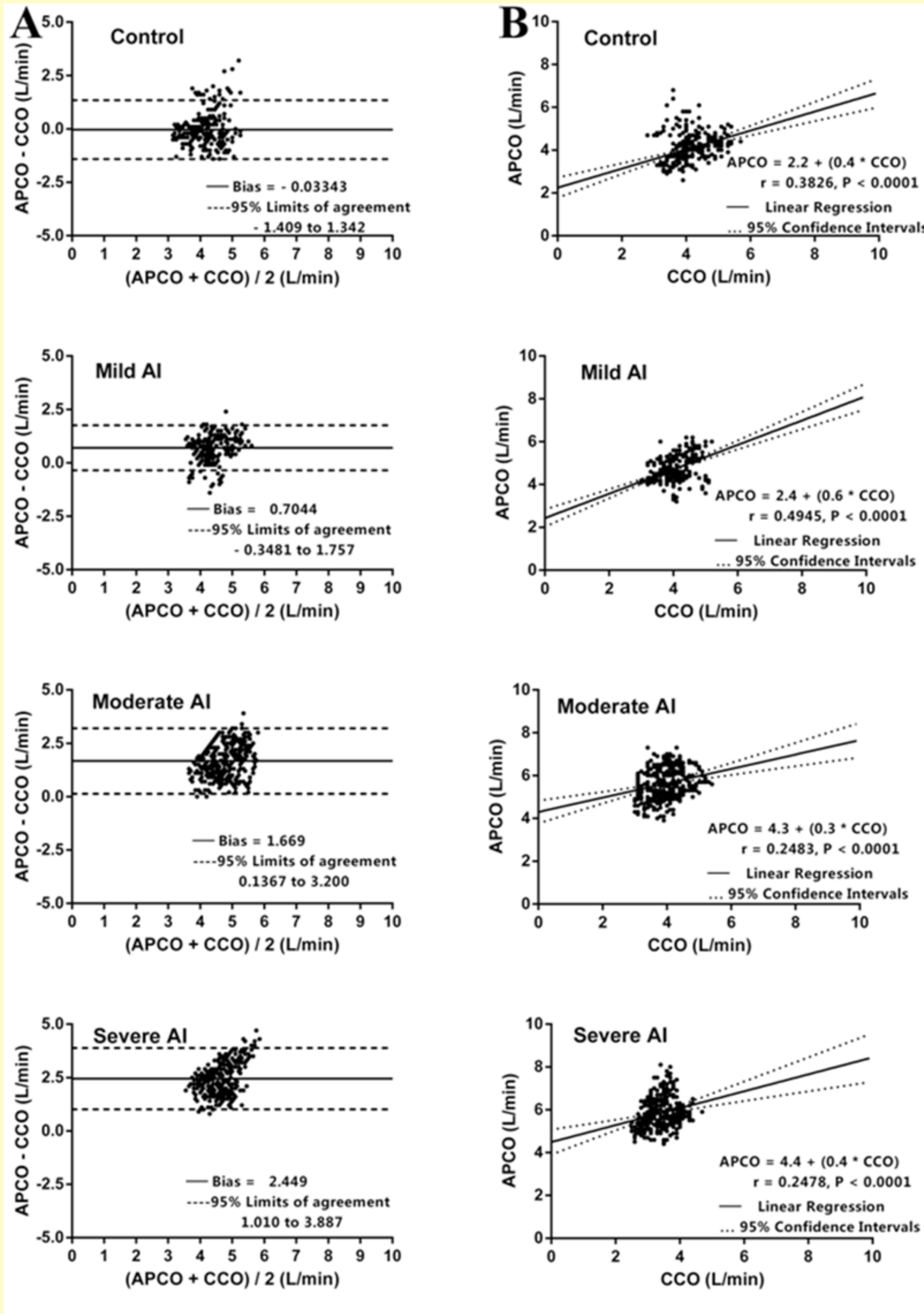

Figure 1: *Bland-Altman plots comparing arterial pressure-based continuous cardiac output (APCO) with continuous thermodilution cardiac output (CCO) (Figure 1A) and correlation between APCO and CCO (Figure 1B) in control group, mild aortic insufficiency (AI) group, moderate AI group and severe AI group.*

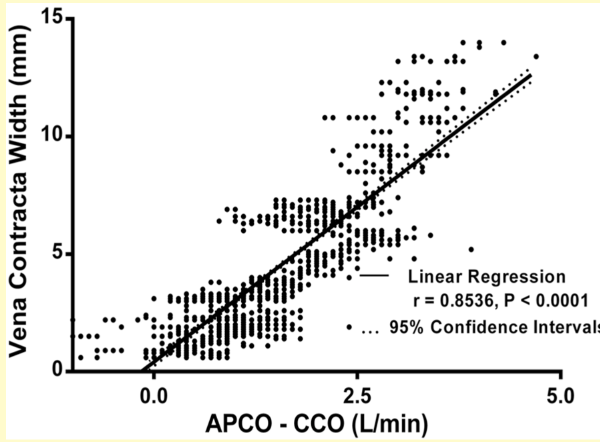

Figure 2: *Correlation between the difference between arterial pressure-based continuous cardiac output (APCO) and continuous thermodilution cardiac output (CCO) and vena contracta width (r = 0.8536, p < 0.0001; vena contracta width = 2.634*APCO-CCO difference + 0.4156).*

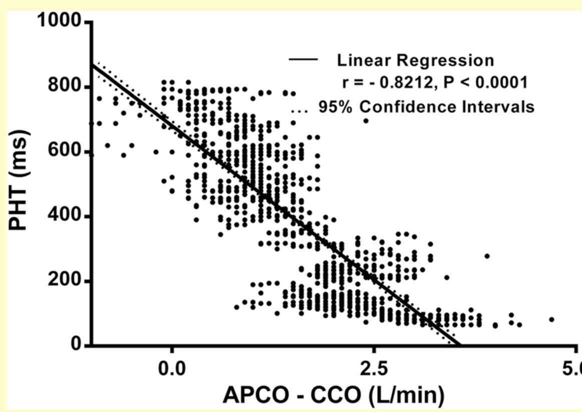

Figure 3: *Inverse Correlation between the difference between arterial pressure-based continuous cardiac output (APCO) and continuous thermodilution cardiac output (CCO) and pressure half-time (r = -0.8212, p < 0.0001; pressure half-time = -190.2*APCO-CCO difference + 680.4).*

Discussion

The findings of the present study extended the finding of the previous researches which demonstrated a poor correlation between cardiac output measurement with the arterial pressure-derived method and continuous thermo dilution method, but demonstrated the good overall agreement [4,11]. The agreement between the two methods was influenced by the degree of aortic insufficiency with a very low bias in elective cardiac surgery patients without aortic valve pathology, but the disparity between the two methods increased when the morphology of the arterial pressure curve has been changed. The pulse pressure in patients with aortic insufficiency is abnormally high because of a low diastolic pressure results from backward flow through the aortic valve during diastole. The slightly increase in the severity of aortic insufficiency further elevated peak systolic velocity demonstrated slightly higher pulse pressure results in slightly higher APCO values compare to CCO. However, the degree of regurgitation is not only depending on the anatomical pathology, but also variable depend on preload and systemic vascular resistance.

also pointed out the presence of genetic variability among Ethiopian coffee selections for green bean physical characteristics and cup quality attributes. The result of the present work was supported by the findings of Antonym and Surip. (2010) [24] who reported that natural coffee processing can produce high quality coffee and creates a highly preferred coffee, compared to full wash, indicating that processing does have an identifiable influence on cup taste.

Because of many reasons especially perioperative hemodynamic optimization of both macro and microcirculation, patients undergoing anesthesia for cardiac surgery need routine invasive monitoring including central venous access and arterial blood pressure, which are able to provide cardiac output from both methods. In addition, the patients always face with the change in preload from patient positioning together with intravascular fluid administration or bleeding, and the change in systemic vascular resistance from both brief physiologic induced fluctuation in systemic vascular resistance such as endotracheal intubation [16] or median sternotomy [10] and the pharmacologic induced alteration in systemic vascular resistance such as inotropic or vasoconstrictor support [4,10]. These factors may interfere with the intra-operative interpretation of the severity of aortic insufficiency. In addition, the results from the previous studies demonstrated that these factors also interfere the agreement between APCO and CCO [4,10,16-17].

Most clinicians assess a patient's cardiac remodeling response to aortic insufficiency as the important clinical parameter. A patient might have moderate to severe aortic insufficiency but if their ventricle does not dilate, the assumption is that the patient may well be able to tolerate this. Similarly, apparently mild aortic insufficiency with manifestation of dysfunctional left ventricular remodeling might be considered a problem. The results of the present study demonstrated a strong correlation between the degree of APCO-CCO difference and the vena contracta width, and a strong inverse correlation between the degree of APCO-CCO difference and the pressure half-time. These correlations showed that calculating such a difference between APCO and CCO was useful and could also be the additional parameter in dynamic evaluation of the severity of aortic insufficiency.

The limitation of this study was whether the chosen semi quantitative echocardiographic parameters which were faster and more convenience for the multiple measurements using the vena contracta width (VC) and the pressure half-time (PHT) were the optimal parameters to describe the severity of AI compare to other more reliable but time-consumed quantitative measurements [9]. In addition, because of the chosen echocardiographic measurement method, the necessary to exclude AI patients with multiple AI jets and patients with eccentric jet is another limitation could not apply the results of the present study to all AI patients. Thus, further studies using other echocardiographic measurement methods should be investigated.

Conclusion

In conclusion, the degree of overestimation of arterial pressure-derived continuous cardiac output with respect to continuous thermo dilution cardiac output can be the additional parameter in perioperative dynamic evaluation of the severity of aortic insufficiency in patients undergoing elective cardiac surgery.

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