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Lack of agreement between esophageal doppler cardiac output measurements and continuous pulse contour analysis during off-pump cardiac surgery

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Abstract

Objective: Transesophageal echo-Doppler cardiac output as well as arterial pulse contour analyses cardiac output are increasingly used for cardiac output monitoring. No data are available whether both techniques may be used interchangeably in patients undergoing cardiac surgery.
Design: Prospective, observational study
Setting: Operating rooms of a university affiliated hospital.
Patients: 30 patients undergoing elective coronary artery bypass grafting surgery.
Interventions: None
Measurements: 900 paired cardiac output measurements were obtained by pulse contour analysis following transpulmonary thermodilution equilibration by the PiCCO system (PiCCO, Pulsion, Munich, Germany) and by the HemoSonic esophageal doppler monitor (HemoSonic 100; Arrow International, Reading, PA). Measurements were performed within the first hour after induction of anesthesia.
Results: Bland-Altman analysis of the complete data set showed a mean difference (bias) of -0.12 l/min (95% CI -0.06 to -0.18) with limits of agreement + 1.8 l/min to -1.6 l/min (upper 95% CI 1.78 to 1.98; lower 95% CI -1.74 to -1.54), the percentage error was + 37% to -44.5%. Transesophageal echo-Doppler cardiac output closely correlated ($r = 0.75$, $p < 0.0001$) with pulse-contour analyses cardiac output.
Conclusions: Several studies have shown the accuracy of calibrated pulse contour cardiac output measurements in patients undergoing cardiac surgery. Thus, the present data question the reliability of transesophageal echo-Doppler derived cardiac output measurements in this setting and may have implications for using transesophageal echo-Doppler during goal-directed hemodynamic optimization.

Key words: cardiac surgery, hemodynamic monitoring, transesophageal echo-doppler

Introduction

Establishing and maintaining adequate cardiac output (CO) and oxygen delivery is a pivotal part of perioperative hemodynamic management in patients undergoing cardiac surgery (1). Traditionally CO monitoring is accomplished by the use of a pulmonary arterial catheter and pulmonary arterial thermodilution (PA-TD), an approach that is still favoured by many clinicians in this field. However, with respect to the potential risks of using a pulmonary arterial catheter there is an increasing interest in alternative methods for determination of CO like transesophageal echo-Doppler (TED) or pulse contour cardiac output (PCCO) devices.

While PCCO systems have been shown to give reliable CO results in comparison with PA-TD in patients undergoing cardiac surgery and have thus been suggested as a valid alternative for the pulmonary arterial catheter (2), the results regarding the accuracy of TED-CO measurements in cardiac surgery patients are conflicting since several very recent studies showed only minor agreement between TED and PA-TD cardiac output measurements in this setting. This is in clear contrast to the results of a recent meta-analysis in critically ill patients.

However, various factors may lead to erroneous CO measurements by PA-TD in patients undergoing cardiac surgery; i.e. tricuspid regurgitation, temperature shifts during cooling and rewarming, etc. Thus it may be hypothesized that the lack of agreement between CO measured with TED and PA-TD in this setting may not be a failure of the TED device but of the comparator: PA-TD. It is of note that studies employing TED driven hemodynamic optimization in cardiac surgery patients are among the few in this field that have shown an improved outcome in terms of reduced complications and/or reduced hospital length of stay (3, 4). No data comparing TED derived CO measurements with PCCO monitoring devices are available. The present study was thus designed to determine the reliability of TED-CO measurement by the HemoSonic monitor (HemoSonic 100; Arrow International, Reading, PA) in comparison with calibrated PCCO analysis by the PiCCO system (PiCCO, Pulsion, Munich, Germany) in patients scheduled for coronary artery bypass (CABG) surgery.

Methods

Following approval by the Ethics Committee of the University of Leipzig and written informed consent, 30 ASA physical status III patients (5 female/25male; age 64.5 ± 9.8 years; weight 82.7 ± 12.5 kg; height 167 ± 34 cm) scheduled for elective CABG surgery were included in this prospective study. A total of 3 ± 1 coronary artery bypasses were performed, including left and/or right internal mammary artery bypass grafting. Patients were excluded if there was increased risk of probe-induced esophageal injury because of known esophageal disease (esophagitis, varices) or serve coagulation disorders. Cardiac arrhythmia (atrial or ventricular) liable to yield erroneous cardiac output determinations either by pulse contour cardiac output analyses or transesophageal echo-Doppler cardiac output measurements were also considered an exclusion criterion. Severe tricuspid regurgiation altering the validity of transpulmonary thermodilution cardiac output determinations for calibarion of the PiCCO system – as well as aortic regurgitation was ruled out by preoperative transthoracic or transesophageal echocardiography.

Following oral premedication with 7.5 mg midazolam and transfer to the operating room, a femoral arterial line for the PiCCO system was inserted during local anesthesia and general anesthesia was induced with sufentanil 0.5-0.7 μg kg BW and propofol 1.5-2 mg kg BW and maintained with remifentanil 0.2-0.4 μg kg/h and propofol 3-5 mg kg/h. Muscle relaxation was achieved with rocuronium 0.6 mg kg BW. All patients were ventilated in a volume controlled mode with a tidal volume of 8 ml/kg BW and respiratory rate adjusted to achieve normocapnia.

Introduction of the TED probe was performed by the nasal route and was easy and atraumatic in all patients. The mean duration of probe introduction and cardiac output recording was 5 ± 3 minutes. No complications related to the use of the TED probe were observed. Following insertion, the probe was adjusted to achieve an optimal position to the descending aorta as determined by M-mode echocardiography according to the instructions of the manufacturer.

Following placement of a central venous line the PiCCO system was calibrated according to the instructions of the manufacturer by transpulmonary thermodilution (TP-TD) with 20 ml cold (4°C) saline and pulse contour measurements were started. To improve the quality of our reference data, the PiCCO system was recalibrated every 15 min.

Thereafter, simultaneous CO measurements from the TED probe and the PiCCO monitor were collected and stored on a personal computer for further analysis. A total of 900 paired cardiac output measurements with both of methods was compared.

Data analyses were performed by MedCalc and SPSS for Windows.

Bland-Altman statistics were calculated on the raw and relative data. For the latter calculations, TED-CO data were expressed as a percentage of PCCO values set to 100%.

A mean percentage error not exceeding 30% was defined to indicate clinically useful reliability of the TED-CO (5). Correlation analyses were performed by linear regression. Data are given as mean ± standard deviation. A p value less than 0.05 indicates statistical significance.

Results

All measurements were performed during stable hemodynamic conditions (table 1). No patient needed inotropic or vasopressor support during the observation period.

Correlation analysis revealed only a moderate correlation coefficient between TED-CO and PCCO of $r = 0.75$ ($p < 0.0001$).

Table 1: Hemodynamics during cardiac surgery

	t1	t2	t3
MAP (mmHg)	64 ± 14 (61 -101)	61 ± 12 (59 - 104)	68 ± 14 (58 - 102)
HR (bpm)	54 ± 12 (46 - 98)	50 ± 10 (44 - 88)	58 ± 14 (49 - 92)
CVP (mmHg)	10 ± 4 (4 - 18)	13 ± 3 (8 - 19)	8 ± 3 (3 - 16)
TED-CO (l*min-1)	3.7 ± 1.2 (2.6 - 8,1)	3.4 ± 1.3 (3.2 - 9.2)	3.2 ± 1.6 (2.3 - 9.9)
TED-SV (ml)	64 ± 28 (31 - 121)	61 ± 37 (44 - 109)	56 ± 43 (29 - 116)
PC-CO ($l*min-1*m^2$)	4.1 ± 1.2 (2.9 - 7.6)	4.4 ± 1.5 (3.1 - 8.6)	3.5 ± 1.2 (3.4 - 8.4)
PC-SV (ml)	68 ± 18 (56 - 115)	71 ± 11 (72 - 108)	64 ± 21 (50 - 121)

Data are mean ± standard deviation and range in parenthesis. T1: First 10 min after induction of anesthesia and beginning of operation procedure. T2: Skin incision and sternotomy. T3: IMA harvesting. MAP: mean arterial pressure; HR: heart rate; CVP: central venous pressure; TED-CO: transesophageal echo-Doppler cardiac output; PC-CO: calibrated arterial pulse contour cardiac output. TED-SV: transesophageal-echo Doppler stroke volume, PC-SV: calibrated arterial pulse contour stroke volume.

Bland-Altman analysis of the complete data set showed a mean difference (bias) of -0.12 l/min (95% CI -0.06 to -0.18) with limits of agreement +1.8 l/min to -1.6 l/min (upper 95% CI 1.78 to 1.98; lower 95% CI -1.74 to -1.54), the percentage error was +37% to -44.5%); The mean cardiac output was 4.1 l/min (range, 2.9 - 9.2 l/min) and the percentage error was +49% to -42%. Analyses at different time points after induction of anesthesia (table 1) revealed the following mean differences (bias) with limits of agreement and percentage error: t1: Mean difference (bias) of -0.33 l/min (95% CI 0.22 to 0.44) with limits of agreement of +2.3 l/min to -1.6 l/min (upper 95% CI 2.18 to 2.57; lower 95% CI -1.81 to -.42), the percentage error was +43.9% to -48.3%),

t2: Mean difference (bias) of -0.20 l/min (95% CI -0.15 to -0.25) with limits of agreement +1.1 l/min to -0.7 l/min (upper 95% CI 1.03 to 1.21; lower 95% CI -0.81 to -0.62), the percentage error was +37% to -44.5%);

t3: Mean difference (bias) of -0.17 l/min (95% CI -0.29 to -0.06) with limits of agreement +1.9 l/min to -2.2 l/min (upper 95% CI 1.66 to 2.07; lower 95% CI -2.42 to -2.01), the percentage error was +46% to -56%).

Discussion

Despite the low bias, the wide limits of agreement question the reliability of CO monitoring by TED in patients undergoing cardiac surgery; a finding that may have relevant clinical implications if TED is applied for goal-directed hemodynamic optimization to fixed goals for cardiac stroke volume (SV) or CO, as recently described by McKendry and coworkers (4). Our observation is in line with recent studies employing PA-TD as a comparator, coming to the conclusion, that TED is unreliable for CO determinations in cardiac surgery patients (6), after cardiac surgery (7), during heart catheterization (8) and that it is often difficult to get an adequate doppler signal (9).

Neverthelees, the acceptability of using TED to track relative changes in CO has been suggested by many perioperative adult studies during liver transplantation (10) and major abdominal surgery (11).

It remains to be determined, why a device being obviously capable of measuring CO adequately in patients undergoing non-cardiac surgery or in critically ill patients fails to give reliable results in the majority of patients undergoing cardiac surgery. A major problem encountered while using an TED probe is the difficulty to obtain a stable and continuous echo doppler signal during surgical manipulation of intrathoracic organs or changes in body position, for example during sidewards positioning and mechanical ventilation with high PEEP (12) that is often necessary if the lung has been compressed by the surgeon for harvesting the internal mammarian arteries (IMA). The TED probe often has to be adjusted in this situations. It is of note, that the largest deviations in CO occurred at time point 3.

However, one possible explanation for the failure of the device to give reliable results has been ruled out by the present study: it is not a problem of the comparator, since the lack of agreement in CO measurements persists if PCCO is used instead for PA-TD.

Consequently and in support of findings from others the present study suggests that TED may not be an ideal tool for optimizing hemodynamics to fixed goals for CO or SV in cardiac surgery patients.

Limitations of the study

While the PiCCO systems has been shown to give reliable CO results in comparison with PA-TD in patients undergoing cardiac surgery and has thus been suggested as a valid alternative for the pulmonary arterial catheter (2), previously published data showed a discrepancy between PA-TD and pulse contour cardiac output technique after cardiac surgery and the authors described that a re-calibration of the PiCCO system did not eliminate

this discrepancy. As a consequence, the authors suggest that pulse contour cardiac output results should always be confirmed with the TP-TD method before major changes in diagnosis or therapy are contemplated (13, 14). Therefore it is conceivable that the wide limits of agreement found in this study are caused, in part, by the inaccuracy of the PiCCO system in this patient population.

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