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BRIEF REPORT

S.G. Sakka
K. Reinhart
A. Meier-Hellmann

Comparison of pulmonary artery and arterial thermodilution cardiac output in critically ill patients

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S.G. Sakka · K. Reinhart · A. Meier-Hellmann (✉)
Department of Anaesthesiology and Intensive Care Medicine, Friedrich-Schiller-University of Jena, Bachstrasse 18, D-07740 Jena, Germany
e-mail: meier-hellmann@anae1.med.uni-jena.de
Tel. + 49(3641)933041
Fax + 49(3641)933256

Abstract *Objective*: We studied the agreement between cardiac output measurements via pulmonary artery thermodilution [CO(PA)], regarded as the current clinical gold standard, and aortic transpulmonary thermodilution [CO(AORTA)].
Design: Prospective clinical study.
Setting: Surgical intensive care unit of a university hospital.
Patients: 37 patients with sepsis or septic shock ($n = 34$) and subarachnoid haemorrhage ($n = 3$).
Measurements and results: We analysed 449 simultaneous cardiac output measurements. All patients were deeply sedated and mechanically ventilated in a pressure controlled mode. Each patient received a 7.5-F five-lumen pulmonary artery catheter and a 4-F aortic catheter with an integrated thermistor. The thermistors of the two different catheters were connected to one computer system (COLD-Z021, Pulsion Medical Systems, Munich, Germany). Linear regression analysis revealed: CO(AORTA) = 0.96 · CO(PA) + 1.02 (l/min) ($r = 0.97$, $p < 0.0001$). CO(AORTA) was consistently higher than CO(PA) with a bias of 0.68 (l/min) and a standard deviation of 0.62 (l/min).
Conclusion: Cardiac output derived from aortic transpulmonary thermodilution is suitable for measurement in the intensive care unit. Measurements of CO(AORTA) are consistent with, but slightly higher than, those obtained from pulmonary artery thermodilution.

Key words Cardiac output · Critically ill patients · Pulmonary artery thermodilution · Transpulmonary thermodilution

Introduction

Cardiac output (CO) is regarded one of the most important haemodynamic variable for the assessment of cardiac function and guidance of therapy in the intensive care setting. Since the clinical introduction of the pulmonary artery catheter (PAC) in 1970 by Swan and Ganz, the pulmonary artery thermodilution technique has become the gold standard for measuring CO. Most commonly, a bolus of cold saline is injected into the right atrium and a thermistor in the tip of the PAC is used to measure the temperature changes. Pulmonary artery CO is calculated by the analysis of the thermodilution curve, using the Stewart-Hamilton equation. Since the PAC is an invasive device, and associated with different potentially fatal cardiac and non-cardiac complications, alternative techniques are being tested. With respect to user-related errors and the influence of respiration on the pulmonary artery CO, measurement of the aortic transpulmonary thermodilution curve for the determination of CO has been proposed. For this technique, a thermistor-tipped catheter is typically placed in the descending aorta via a femoral artery sheath. Thus, we analysed the agreement in CO determinations between these two techniques: pulmonary artery [CO(PA)] and aortic transpulmonary thermodilution [CO(AORTA)] in critically ill patients.

Table 1 Demographic data (*SAPS* Simplified Acute Physiology Score, *SOFA* Sepsis-relate Organ Failure)

Men/women (*n*)	25/12
Age (years)	25–86 (62 ± 14)
Height (cm)	158–188 (172 ± 8)
Weight (kg)	60–120 (85 ± 14)
Body surface area (m^2)	1.62–2.24 (1.97 ± 0.17)
SAPS II	56 ± 14
SOFA score	15 ± 3

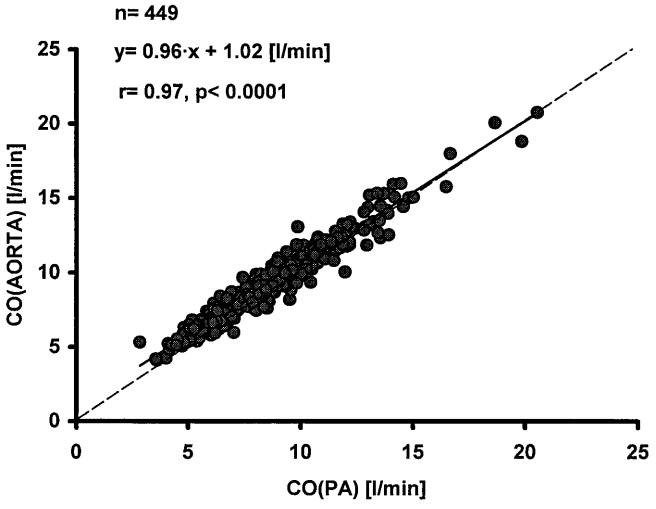

Fig. 1 Linear regression analysis for aortic transpulmonary *CO*(*AORTA*) and pulmonary artery *CO*(*PA*) thermodilution CO in 37 critically ill patients. Line of identity is *dashed*

Patients and methods

After approval by our institutional ethics committee, 37 patients (25 males and 12 females) were studied. Thirty-four patients suffered from sepsis or septic shock (definition according to the criteria of the ACCP-SCCM consensus conference) and 3 patients from subarachnoid haemorrhage. The demographic data for the patients are listed in Table 1. A total number of 449 single CO measurements was analysed (1–29 per patient, mean 12 ± 9). All patients were deeply sedated with fentanyl (0.6 mg/h) and dehydroperidol (7.5 mg/h). If necessary, midazolam was administered in a dosage up to 15 mg/h. Patients were mechanically ventilated in a pressure-controlled mode (inspiratory:expiratory ratio = 1:1) and positive end-expiratory pressure was adjusted individually according to blood gas monitoring. Each patient received a 7.5-F five-lumen PAC (Edwards Swan Ganz, CCO/ SvO_2, Model 744H 7.5 F, Baxter Healthcare, Irvine, Calif., USA) for the continuous measurement of CO and a 4-F aortic catheter with an integrated thermistor (Pulsiocath 4F PV 2024L, Pulsion Medical Systems, Munich, Germany). The tip of the catheter was placed at the infradiaphragmatic level as assumed from individual body measurements. Bolus injections used cooled (0–6 °C) 0.9 % saline (15–17 ml per bolus). Injections were done manually and randomly throughout the respiratory cycle. The thermistors of the two different catheters were connected to one computer system (COLD-Z021, Pulsion Medical Systems, Munich, Germany) which, based on the respective thermodilution curves, calculated pulmonary artery and aortic transpulmonary CO. At least two repetitive measurements were performed. Blood temperature was in a range between 32.6 and 40.5 °C.

All results are expressed as mean ± standard deviation. The relation between CO(AORTA) and CO(PA) was analysed by linear regression and the Bland-Altman method. Statistical analysis was performed using software SPSS for Windows, version 6.1.2. Statistical significance was considered to be at $p < 0.01$.

Results

The CO range was 4.0 to 20.5 (l/min) for CO(PA) and 4.3 to 20.8 (l/min) for CO(AORTA). Linear regression analysis revealed CO(AORTA) = 0.96 · CO(PA) + 1.02 (l/min) ($r = 0.97$, $p < 0.0001$) (Fig. 1). The analysis according to Bland-Altman showed a good agreement between both techniques. CO(AORTA) was consistently higher than CO(PA) with a bias of 0.68 (l/min) and a standard deviation of 0.62 (l/min) (Fig. 2).

Discussion

These data show that measurement of CO from CO(AORTA) is consistent with measurements by the current clinical gold standard, i. e. CO(PA). Previous animal experiments [1, 2] and clinical studies [3, 4] reported a good correlation between the two techniques. However, aortic transpulmonary CO is most often measured higher than the corresponding pulmonary artery CO. The reasons for this finding are thought to be, firstly, loss of the cold and, secondly, that the right heart CO is lower than left heart CO due to a cold-induced reduction in heart rate. Although Lewis et al. [3] described a 9 % loss of the injected thermal indicator before reaching the femoral detection, Böck et al. [2] showed in an animal experiment that early recirculation of the cold is responsible for the broadened thermodilution curve in the aorta, thus, leading to about 3–4 % higher values for CO. Since other studies did not find an indicator loss [5, 6], the transient reduction in heart rate by the cold injection, which has less influence on the CO(AORTA) due to the longer appearance time, is considered to be more responsible for the somewhat lower values by the CO(PA) [7].

Surprisingly, there is only one very recent study, by Gust et al. [8] in 75 intensive care patients undergoing coronary artery bypass surgery that showed a poorer correlation between the two techniques ($r = 0.73$). They, too, found a consistently higher CO when measured in the aorta. They concluded that while in some patients aortic transpulmonary CO does offer an attractive, reliable and safe method, in most patients it will not replace the conventional CO(PA). However, methodological limitations may be responsible for this dis-

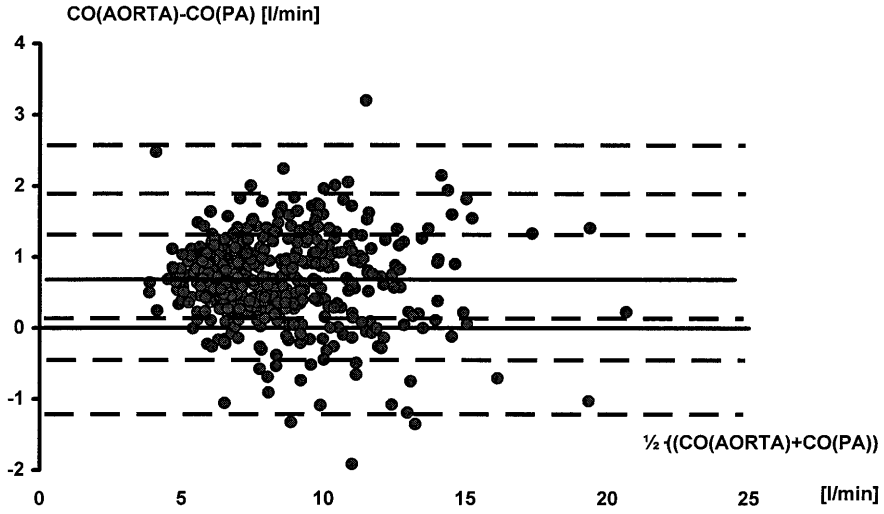

Fig. 2 Agreement between aortic transpulmonary *CO(AORTA)* and pulmonary artery *CO(PA)* thermodilution CO according to Bland-Altman analysis. Each *dashed line* indicates 1 SD, mean bias was 0.68 (l/min)

crepancy. Firstly, Gust et al. [8] used two different CO measuring systems. In contrast, in our study we used the same CO computing system for the aortic transpulmonary and the PAC measurements. Secondly, since the SD seems to be larger in the postoperative weaning period, including periods with positive pressure ventilation and spontaneous breathing, and therefore was associated with marked changes in intrathoracic pressure, one could speculate that this finding is due to the particularly high sensitivity of pulmonary CO to respiratory changes. Pulmonary artery CO is still considered to be the clinical gold standard, though previous studies revealed that it exhibits a cyclic modulation related to ventilation [9]. In this study, the 5D was more than 15% of the mean and the values were dependent upon the moment of injection during a single ventilatory cycle.

In their discussion, Gust et al. [8] mentioned a temperature drift for the aortic transpulmonary measurement several hours after the extracorporeal circuit, which in our view should also have been present in the pulmonary artery. According to the manufacturer, the COLD-Z021 system automatically corrects linearly for drift of both baseline temperatures. A further reason for the difference between the two CO measuring techniques in the study by Gust et al. [8] may have been the use of too little injection volume. In our study, we used at least 15 ml, which has been recommended for CO(AORTA). Most recently, Godje et al. [4] analysed 150 measurements of cardiac index in 30 patients 3 h after coronary artery bypass surgery. Also using the COLD-Z021 system for the measurement of CO(AORTA) and a second, different commercial system for the measurement of CO(PA), they found a correlation coefficient of $r = 0.96$ with a bias of 0.16 (l/min per m^2).

In principle, CO(AORTA) requires a central venous line for the injection of cooled saline and a femoral arterial catheter. However, central venous catheterisation is necessary in most intensive care patients due to other reasons, and femoral artery catheterisation, which allows continuous haemodynamic monitoring and blood sampling, has been shown to be safe in critically ill patients [10]. Thus, this technique is considered less invasive in comparison to pulmonary artery catheterisation. Nevertheless, in patients with severe arteriosclerosis or aneurysms this technique is contraindicated.

In conclusion these data support the majority of the previous studies which have found that the measurement of CO by CO(AORTA), when an appropriate injection volume is used, is consistent with, but slightly higher than, the current clinical gold standard, CO(PA).

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