

RESEARCH PAPER

Continuous versus intermittent thermodilution for cardiac output measurement during alveolar recruitment manoeuvres in sheep

Tamas D Ambrisko, Paul Coppens & Yves Moens

Division of Anaesthesiology and perioperative Intensive Care, University of Veterinary Medicine, Vienna, Austria

Correspondence: Tamas D Ambrisko, Division of Anaesthesiology and perioperative Intensive Care, University of Veterinary Medicine, Veterinärplatz 1, A-1210 Vienna, Austria. E-mail: Tamas.Ambrisko@vetmeduni.ac.at

Abstract

Objective To evaluate interchangeability of a thermodilution based STAT mode continuous cardiac output (CCO) measurement method with bolus thermodilution (BTD).

Study design Randomized crossover study.

Animals Ten 9 month old healthy male sheep.

Methods Each sheep was anaesthetized twice for laparoscopy. On one occasion mechanical ventilation was used immediately after anaesthetic induction (IPPV treatment) and on the other occasion the start of IPPV was delayed and two periods of alveolar recruitment manoeuvres were also performed (RM treatment). Cardiac output (CO) was measured simultaneously with both CCO and BTD at 6 time points. Data were analysed using difference versus mean plots. *A priori* limits of acceptance were set at $\pm 30\%$ of the mean of every paired measurement. If $< 5\%$ of the data fell outside of these limits (Chi-square test, $p < 0.05$) the interchangeability of methods was accepted. Proportions of data outside of these limits were also compared between treatments (Fisher's test, $p < 0.05$). Cardiac output data from each treatment and measurement method were also analyzed separately with one-factorial ANOVA and Bonferroni test ($p < 0.05$).

Results A total of 119 measurements were obtained. Cardiac output ranged from 1.9 to 10.4 L minute⁻¹ (CCO) and from 1.1 to 9.8 L minute⁻¹ (BTD). The bias and limits of agreement were 0.5 ± 1.9 L minute⁻¹. More than 5% of all data fell outside of the limits of acceptance (24/119), and a larger proportion fell outside of these limits in the RM (20/59) compared to the IPPV treatment (4/60). The Bonferroni test detected significant decreases of CO over time in both treatments when measured with BTD but not with CCO.

Conclusions and clinical relevance The STAT mode CCO method is not interchangeable with BTD during acute haemodynamic changes caused by recruitment manoeuvres, thus the results of STAT mode CCO should be interpreted with caution because decreases in CO may not be detected.

Keywords alveolar recruitment manoeuvres, cardiac output, haemodynamic monitoring, sheep, thermodilution.

Introduction

The measurement of cardiac output (CO) is a cornerstone of haemodynamic evaluation in experimental as well as in clinical situations. In the critically ill patient, CO measurement can aid in therapeutic decision-making in anaesthesia and

intensive care. Since the development of the balloon-tipped pulmonary artery catheter (Swan et al. 1970), bolus thermodilution (BTd) has become the reference method for CO measurement (Nishikawa & Dohi 1993) and has been shown to be a reliable technique in sheep (Renner et al. 1993). This method necessitates intermittent interventions to perform bolus injections of fluid and usually the mean of 2–4 measurements is taken to improve precision (Nishikawa & Dohi 1993).

In 1990, a newer method using the thermodilution principle, with heat as thermal indicator, was introduced which allowed continuous cardiac output (CCO) measurement (Yelderman 1990). For this purpose, the Swan-Ganz catheter was equipped with a thermal filament which is intermittently heated in a random on-off pattern. The signal-to-noise ratio of this system is low because the supplied heat (signal) must be kept low to avoid thermal damage. Additionally, the thermal 'noise' is relatively high because there are physiological blood temperature variations in the pulmonary artery, which depend mainly on ventilation and circulation (Wessel et al. 1966). To overcome this problem, the stochastic system identification technique was used to compute thermal indicator dilution curves (Yelderman 1990). The CO data are calculated from the area under these curves and the monitor's display is updated with the new results every 30–60 seconds. By default, the average CO of the past 3–6 minutes is displayed on the monitor (trend mode) in order to suppress artefacts. Once the pulmonary catheter is positioned this method does not require further manipulation and potential errors, such as those induced by repeated injection of fluid (Wetzel & Latson 1985), can be excluded. This technique may thus be more suitable for trend analysis of CO than BTd.

Using the trend mode, good correlations were found between CCO and BTd methods in sheep during slow haemorrhage (Yelderman et al. 1992) and in a septic shock model (Sun et al. 2002) but poor correlation was found between CCO compared to pulmonary artery blood flow in a canine study modelling acute haemodynamic changes (Poli de Figueiredo et al. 1999). In order to improve the response time of the CCO measurements, the STAT mode has been incorporated in the monitor. During STAT mode of operation, CO measurements are also updated every 30–35 seconds and the values depend on previous measurements to some degree (for suppression of artefacts) but the software

algorithm does not contain a 3–6 minute moving average filter (Lazor et al. 1997). Good correlations were found between STAT or trend modes of CCO measurements and BTd during stable haemodynamic conditions (Lazor et al. 1997). However, according to the authors' knowledge, the STAT mode of CCO has not been compared to BTd during acute haemodynamic changes.

The aim of this study was to compare CO measurements obtained with the STAT mode of CCO and with the BTd methods in sheep during acute haemodynamic changes induced by alveolar recruitment manoeuvres, mechanical ventilation and capnoperitoneum.

Materials and methods

Ten 9 month old male sheep, with a body weight of 38.5 ± 2.5 kg (mean $\pm$ SD) were the subjects of the study. The sheep were owned by the University. They were housed on campus (both in- and outdoors) and fed grass, hay and corn. The animals were considered healthy after physical examination and routine haematological and biochemical blood analysis. This study was a part of a larger research project including surgical, ventilation and pharmacological research. The study protocol was approved by the institutional ethics committee and also by the Austrian government (GZ 68.205/0168-BrGt/2006).

Each sheep underwent anaesthesia twice, once for laparoscopic cystotomy and two weeks later for a control laparoscopy. A different ventilation strategy was used at each occasion in a randomized order: 1) mechanical ventilation was initiated immediately after induction of anaesthesia and maintained throughout the anaesthetic procedure (IPPV treatment); and 2) the animals were initially breathing spontaneously and mechanical ventilation was started 20 minutes after capnoperitoneum was established. This was followed by two occasions of alveolar recruitment manoeuvre at 45 and 55 minutes after the start of capnoperitoneum (RM treatment). Animals were ventilated during both treatments with a mechanical ventilator (Siemens Servo 300, Sweden) using 12 mL kg^{-1} tidal volume at 20 breaths minute^{-1} (baseline ventilation). This ICU ventilator was driven with compressed air and it was connected to the breathing circuit (replacing the reservoir bag) via a long corrugated hose to reduce admixture of gases. Recruitment manoeuvres consisted of stepwise increases in peak

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