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Effects of one-lung ventilation on thermodilution-derived assessment of cardiac output

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Editor's key points

- This study compared the reliability of cardiac output (CO) measurements during one-lung ventilation (OLV).
- CO measurements during OLV were more accurate using a pulmonary artery compared with a transcardiopulmonary thermodilution technique.
- Both techniques reported trend values reliably during hypovolaemia and normovolaemia.

Background. Cardiac output (CO) monitoring can be useful in high-risk patients during one-lung ventilation (OLV), but it is unclear whether thermodilution-derived CO monitoring is valid during OLV. Therefore, we compared pulmonary artery (CO_{PATD}) and transcardiopulmonary thermodilution (CO_{TPTD}) with an experimental reference in a porcine model.

Methods. CO_{PATD} and CO_{TPTD} were measured in 23 pigs during double-lung ventilation (DLV) and 15 min after the onset of OLV, during conditions of normovolaemia and after haemorrhage. An ultrasonic flow probe placed around the pulmonary artery (CO_{PAFP}) was used for reference.

Results. The range of CO in these experiments was 1.5–3 litre min^{-1}. Normovolaemia: during DLV and conditions of normovolaemia, the mean (95% limits of agreement) bias for CO_{PATD} compared with CO_{PAFP} was −0.05 (−0.92 and 0.83) litre min^{-1}, and 0.58 (−0.40 and 1.55) litre min^{-1} for CO_{TPTD}. During OLV, the bias for CO_{PATD} remained unchanged at 0.08 (−0.51 and 0.66) litre min^{-1}, $P=0.15$, and the bias for CO_{TPTD} increased significantly to 0.85 (0.05 and 1.64) litre min^{-1}, $P=0.047$. Hypovolaemia: during DLV, the bias for CO_{PATD} compared with CO_{PAFP} was 0.22 (−0.20 and 0.66) litre min^{-1} and for CO_{TPTD} was 0.60 (0.12 and 1.10) litre min^{-1}. There was no significant change of bias during OLV for CO_{PATD} [0.30 (−0.10 and 0.70) (litre min^{-1}), $P=0.25$] or bias CO_{TPTD} [0.72 (0.21 and 1.22) (litre min^{-1}), $P=0.14$]. Trending ability during OLV, quantified by the mean of angles θ, showed good values for both CO_{PATD} ($\theta=11.2^{\circ}$) and CO_{TPTD} ($\theta=1.3^{\circ}$).

Conclusions. CO_{TPTD} is, to some extent, affected by OLV, whereas CO_{PATD} is unchanged. Nonetheless, both methods provide an acceptable estimation of CO and particularly of relative changes of CO during OLV.

Keywords: cardiac output; hypovolaemia; intraoperative monitoring; one-lung ventilation; physiological monitoring; thermodilution

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One-lung ventilation (OLV) is performed routinely during thoracic surgery[1] and is usually well tolerated. Nevertheless, some of the consequences of OLV, such as increased pulmonary vascular resistance (PVR) induced by hypoxic pulmonary vasoconstriction, increased ventilation pressures, hypoxaemia, or hypercarbia, can cause haemodynamic changes, which can potentially lead to circulatory instability.[2 3] Therefore, cardiac output (CO) monitoring can be a useful tool to optimize haemodynamic management in patients undergoing major thoracic surgery.[4 5] CO estimation by pulmonary artery thermodilution (CO_{PATD}) using a pulmonary artery catheter or transcardiopulmonary thermodilution (CO_{TPTD}) is frequently used for this purpose during surgery and in intensive care.

However, there are a few data showing the validity of CO measurement by pulmonary artery thermodilution and transcardiopulmonary thermodilution during OLV, and these techniques have not been compared with an experimental reference standard. This reference standard is provided by an ultrasonic flow probe placed around the pulmonary artery (CO_{PAFP}) because of its high accuracy ($\pm$1–2%) and reproducibility and also its fast response.[6–9] The validation of thermodilution methods is of special interest, since OLV potentially can influence the principles of these methods. This holds true in particular for CO_{TPTD}, since hypoxic pulmonary vasoconstriction in the deflated lung might have an influence on transit time and thus the contact time of the indicator with the surrounding tissue,

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leading to altered indicator concentrations over time at the site of the detection. Consequently, the validity of using thermodilution-derived CO measurements in clinical practice for monitoring and guidance of therapy during OLV is unclear.

Therefore, the aim of this experimental animal study was to assess the validity of CO measurements by pulmonary and transcardiopulmonary thermodilution during OLV in two different haemodynamic conditions. We chose normovolaemia and hypovolaemia to represent a wide variation in CO and compared the data with an experimental reference of measurement by a pulmonary artery flow probe.

Methods

The study was approved by the local governmental commission on the care and use of animals. Twenty-three domestic pigs were studied. The animals received care in compliance with the 'Guide for the Care and Use of Laboratory Animals' (National Institutes of Health publication No. 86-23, revised 1996).

Anaesthesia and instrumentation

Twenty-three German domestic (Landrace) pigs in overt good health with a body weight of 35–40 kg were studied. The animals were allowed to fast overnight and premedicated with an i.m. injection of ketamine (10 mg kg^{-1}), azaperone (4 mg kg^{-1}), midazolam (0.5 mg kg^{-1}), and atropine sulphate (1 mg). An i.v. access was established in an ear vein and anaesthesia was maintained by continuous infusion of fentanyl (0.05 mg kg^{-1} h^{-1}) and propofol (10 mg kg^{-1} h^{-1}). Thereafter, tracheotomy and placement of a tracheal tube (8.5 mm) were performed. After securing the airway, a pancuronium (0.1 mg kg^{-1}) was injected i.v. to facilitate surgical preparation. The animals were monitored with a five-lead ECG and pulse oximetry. The lungs were ventilated using volume-controlled ventilation (Zeus, Drägermedical®, Germany, using tidal volumes 10 ml kg^{-1}; inspiration:expiration ratio 1:1.6; PEEP 5 cm H_2O, and inspiratory oxygen fraction 0.5). During OLV, tidal volumes were reduced to 6 ml kg^{-1}. End-expiratory P_{CO_2} was maintained at 5.3–6 kPa by adjusting ventilatory rate. An i.v. infusion of saline was infused at a rate of 13 ml kg^{-1} h^{-1} to maintain hydration. The animals were placed in the supine position for catheter placement and surgical preparation. An 8.5 Fr central venous catheter was introduced into the right internal jugular vein for drug and fluid administration, and for central venous pressure measurement. An introducer sheath (8.5 Fr) was placed into the right external jugular vein and pulmonary artery catheter (7 Fr, Intra Special Catheters®, Germany) advanced for CO_{PATD} measurement and for the measurement of mean pulmonary artery pressure (mPAP) and PVR. Further, another introducer sheath (8.5 Fr) was placed into the left external jugular vein for volume withdrawal. Finally, a thermistor-tipped catheter (5 Fr, PiCCO Catheter, Pulsion®, Munich, Germany) was placed into the femoral artery for detection of transcardiopulmonary thermodilution. All introducer sheaths and the central venous catheter were placed surgically by direct preparation of the relevant vessel, except the femoral arterial catheter, which was placed percutaneously. Body temperature was measured using the arterial catheter and kept constant by the use of warming blankets and pre-warming of infusions, if required.

After thoracic skin incision, a median sternotomy was performed. After preparation of mediastinal tissue and surgical haemostasis, the pericardium was incised longitudinally in the midline and tacked to the chest wall. Mediastinal fatty tissue was dissected by monopolar electric scalpel, and pulmonary artery and the ascending aorta were exposed. A perivascular ultrasonic flow probe (18 mm, Medistim®, Norway) was placed around the pulmonary artery for reference CO measurement.[10 11] A sufficient amount of acoustic gel was placed between pulmonary artery and flow probe to avoid any air hindering the accurate flow probe measurement.

Measurements and experimental protocol

Normovolaemia was established by the infusion of hetastarch colloids 5 ml kg^{-1} (Voluven 130/0.4 6%, Fresenius Kabi®, Germany) at intervals of 5 min until stroke volume variation (SVV) measured by arterial pulse contour analysis ($PiCCO_2$, Pulsion) was below 10%. The measurement protocol was then started and the first measurements were performed during double-lung ventilation (DLV) and normovolaemia (M1). All pulmonary and transcardiopulmonary thermodilution measurements were assessed by three sequential central venous injections of 10 ml of cold saline solution (<8°C) randomly given throughout the respiratory cycle via the central venous port of the pulmonary artery catheter. All thermodilution curves were examined, and measurements were accepted if none of the three consecutive values differed by more than 10% from the mean. Simultaneously to every thermodilution measurement, CO of the flow probe was recorded using EMKA software (EMKA Technologies®, Paris, France). PVR was calculated by the formula PVR (dyn s cm^{-5})=$(PAP_{mean}-PCWP)\times CO^{-1}\times 80$ using pulmonary artery catheter parameters.

Afterwards, OLV was initiated using a 5 Fr endobronchial blocker (CookMedical, Bloomington, IN, USA) placed into the left main bronchus under bronchoscopic guidance to achieve deflation of the left lung. After an equilibration period of 15 min, measurements were repeated (M2). OLV was terminated and DLV was re-established. After another 15 min for equilibration, hypovolaemia was induced by withdrawal of 20 ml kg^{-1} of blood over 30 min. Subsequently, measurements were repeated (M3) and again OLV was implemented. After 15 min, measurement M4 was carried out. After completion of measurements, the animals were killed by fast injection of 50 mmol KCl during deep anaesthesia.

Statistical analysis

Data were analysed using SigmaPlot 12 (Systat Software Inc., San Jose, CA, USA) and GraphPad Prism 5 (GraphPad Software, La Jolla, CA, USA). Power analysis revealed that 22