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RESEARCH PAPER

Electrical velocimetry for noninvasive cardiac output and stroke volume variation measurements in dogs undergoing cardiovascular surgery

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Abstract

Objective To compare electrical velocimetry (EV) noninvasive measures of cardiac output (CO) and stroke volume variation (SVV) in dogs undergoing cardiovascular surgery with those obtained with the conventional thermodilution technique using a pulmonary artery catheter.

Study design Prospective experimental trial.

Animals Seven adult Beagle dogs with a median weight of 13.6 kg.

Methods Simultaneous, coupled cardiac index (CI; CO indexed to body surface area) measurements by EV (CI_{EV}) and the reference pulmonary artery catheter thermodilution method (CI_{PAC}) were obtained in seven sevoflurane-anaesthetized, mechanically ventilated dogs undergoing experimental open-chest cardiovascular surgery for isolated right ventricular failure. Relationships between SVV or central venous pressure (CVP) and stroke volume (SV) were analysed to estimate fluid responsiveness. Haemodynamic data were recorded intraoperatively and before and after fluid challenge.

Results Bland–Altman analysis of 332 matched sets of CI data revealed an overall bias and precision of -0.22 ± 0.52 L minute^{-1} m^{-2} for CI_{EV} and CI_{PAC} (percentage error: 30.4%). Trend analysis showed a concordance of 88% for CI_{EV}. SVV showed a significant positive correlation ($r^2 = 0.442$, $p < 0.0001$) with SV changes to a volume loading of 200 mL, but CVP did not ($r^2 = 0.0002$, $p = 0.94$). Better prediction of SV responsiveness (rise of SV index of $\geq 10\%$) was observed for SVV (0.74 ± 0.09; $p = 0.014$) with a significant area under the receiver operating characteristic curve in comparison with CVP (0.53 ± 0.98; $p = 0.78$), with a cut-off value of 14.5% (60% specificity and 83% sensitivity).

Conclusions and clinical relevance In dogs undergoing cardiovascular surgery, EV provided accurate CO measurements compared with CI_{PAC}, although its trending ability was poor. Further, SVV by EV, but not CVP, reliably predicted fluid responsiveness during mechanical ventilation in dogs.

Keywords cardiac output, cardiovascular surgery, dog, electrical velocimetry, fluid therapy, haemodynamic monitoring.

Introduction

Early continuous haemodynamic assessment according to cardiac output (CO) is useful in the intensive care unit for monitoring patients with heart failure or shock and for the titration of cardiovascular drugs and fluids. Use of a

pulmonary artery (PA) catheter is an established method for CO measurement, but has been criticized because of its cost and invasiveness (Vincent 2012; Thiele et al. 2015), and its use is declining in favour of less invasive alternatives, particularly in infants and children (Norozi et al. 2008; Cote et al. 2015; Ma et al. 2015; Torigoe et al. 2015). This is also the case in small animals, in which the use of CO monitoring techniques is not common clinically, but remains limited to research settings and applied to the assessment of the cardiovascular effects of drugs or medical devices (Mutoh et al. 1997; Mutoh 2007; Heerdt et al. 2011; Morgaz et al. 2014; Muir et al. 2014; Pavlisko et al. 2016).

Electrical velocimetry (EV) has been tested as a new noninvasive method of monitoring beat-to-beat stroke volume (SV) and CO in human patients (Bernstein & Lemmens 2005). This technique is based on the conductivity of the blood flow changes in the aorta during the cardiac cycle and uses four dual electric sensors placed on the neck and chest (Schmidt et al. 2005). Recent studies have demonstrated the clinical utility of EV, particularly in human neonatal and paediatric patients (Tomaske et al. 2008; Blohm et al. 2014; Grollmuss & Gonzalez 2014; Torigoe et al. 2015) in whom catheter-based haemodynamic monitoring is rarely performed because of technical difficulties and invasiveness. In addition, the EV method also allows continuous tracking of a dynamic preload indicator, SV variation (SVV). Although the usefulness of continuous SVV monitoring to predict fluid responsiveness using other noninvasive methods (e.g. bioreactance) has been demonstrated in children (Lee et al. 2014; Vergnaud et al. 2015), data obtained in dogs using EV are limited (Heerdt et al. 2011). Despite its ease of use, the role of EV in managing small animals undergoing high-risk surgery has yet to be determined.

We hypothesized that if CO and SVV incorporated with the noninvasive monitoring device were available, then safer and more practical protocols for fluid and haemodynamic management would be established in veterinary anaesthesia and intensive care. We therefore conducted a pilot study to investigate the use of EV monitoring compared with conventional thermodilution techniques using a PA catheter in dogs experiencing experimentally induced acute right heart failure.

Materials and methods

Animals

Seven purpose-bred, adult (aged 3 years) male Beagle dogs with a median weight of 13.6 kg (interquartile range: 9.8–15.9 kg) were enrolled in the study. The dogs were determined to be healthy based on a physical examination, complete blood cell count and serum biochemistry profile. Animals were fasted for 12 hours prior to each experiment, but given free access to water. They were housed and cared for according to the guidelines of the Association for Assessment and Accreditation of Laboratory Animal Care. The Animal Care and Use Committee of the Tohoku University Graduate School of Medicine approved this study (no. 116/2014).

Anaesthesia protocol and instrumentation

After intramuscular premedication with ketamine (1 mg kg^{-1}; Ketalar; Daiichi Sankyo Propharma Co. Ltd, Japan) and fentanyl (10 μg kg^{-1}; Fentanyl; Daiichi Sankyo Propharma Co. Ltd), a 22 gauge catheter (Insyte-W; Becton, Dickinson & Co., UT, USA) was placed in a cephalic vein. Anaesthesia was induced with propofol (4–7 mg kg^{-1}; Propofol; Maruishi Pharmaceutical Co. Ltd, Japan) administered intravenously (IV) over 5 minutes. Rocuronium (0.5 mg kg^{-1}; Eslax; MSD KK, Japan) was administered as a bolus IV before tracheal intubation and a constant rate infusion (CRI) IV of rocuronium (0.2 mg kg^{-1} $hour^{-1}$) was started. Intubation was performed approximately 40–60 seconds after the initial rocuronium injection and the dogs were placed in left lateral recumbency for instrumentation. The endotracheal tube was connected to a semi-closed rebreathing circle system and the lungs were mechanically ventilated [tidal volume (V_T): 10 mL kg^{-1}; respiratory rate (f_R): 10–14 breaths $minute^{-1}$] with a volume-controlled ventilator (COMPOSβ EV; Metran Co. Ltd, Japan) to achieve an end-tidal carbon dioxide tension ($P_E'CO_2$) of 30–41 mmHg (4.0–5.5 kPa). Anaesthesia was maintained with sevoflurane (1.0–2.0%; Sevofrane; Maruishi Pharmaceutical Co. Ltd) in 60% oxygen with a CRI of fentanyl infused at 12.5–30.0 μg kg^{-1} $hour^{-1}$ titrated according to the animal's responses to the surgical procedure and the experimental guidelines for an adequate depth of

