The Veterinary Journal 197 (2013) 800–805

Contents lists available at SciVerse ScienceDirect

The Veterinary Journal

journal homepage: www.elsevier.com/locate/tvjl

Effects of fluid load on cardiovascular function during stepwise lung recruitment manoeuvre in healthy dogs

S. Canfrán [a,*], I.A. Gómez de Segura [a], R. Cediel [a], J. García-Fernández [b]

[a] Department of Animal Medicine and Surgery, Veterinary Faculty, Complutense University of Madrid, Avda. Puerta de Hierro s/n, Madrid 28040, Spain
[b] Anaesthesiology and Intensive Care Department, Puerta de Hierro University Hospital, Manuel de Falla 1, Majadahonda, Madrid 28222, Spain

ARTICLE INFO

Article history:
Accepted 12 May 2013

Keywords:
Canine anaesthesia
Cardiac output
Lung recruitment
Mechanical ventilation

ABSTRACT

The aim of this study was to evaluate the effects of a stepwise lung recruitment manoeuvre (RM) on cardiac output (CO) in mechanically ventilated dogs, with or without a previous fluid load. Eight healthy adult Beagle dogs were enrolled in a prospective crossover study. Following sedation with dexmedetomidine and methadone, anaesthesia was induced with propofol and maintained with isoflurane. CO (thermodilution method) and direct arterial blood pressure were monitored. The dogs were mechanically ventilated in a volume-controlled mode (tidal volume, VT = 10 mL/kg; positive end-expiratory pressure [PEEP] = 0 cm H_2O) until normocapnia was achieved (end tidal CO_2 35–45 mmHg). The RM was then performed in a pressure-controlled mode, with progressive increases of the PEEP and end-inspiratory pressure of 5 cm H_2O, until 15 cm H_2O and 30 cm H_2O were reached, respectively. After the RM, the ventilatory mode was returned to volume-control, and the PEEP was sequentially decreased to 10, 5 and 0 cm H_2O. Baseline ventilation was maintained for 30 min. Next, 10 mL/kg of lactated Ringer's solution was administered within 10 min, prior to a second RM. The CO was determined before each RM (baseline) and at each pressure step. A repeated measures ANOVA test was used to compare data.

Compared to baseline, CO decreased during the RM in both groups. However, there was a significantly higher CO during the second RM at the highest pressure step ($P < 0.05$) and during all decreasing pressure steps ($P < 0.05$). In conclusion, a previous crystalloid fluid load could reduce the impact of a RM on CO in healthy dogs.

Introduction

Recruitment manoeuvres (RMs) are employed during general anaesthesia to reverse lung atelectasis (Bendixen et al., 1963) and are based on increased end-inspiratory pressure (EIP) to open collapsed alveoli; the first manoeuvre is followed by the application of enough positive end-expiratory pressure (PEEP) to keep the alveoli open after the RM (Lachmann, 1992).

The main types of RMs, sustained inflation or stepwise manoeuvres, improve gas exchange and lung mechanics in both humans (Bendixen et al., 1963; Rothen et al., 1993; Neumann et al., 1999; Tusman et al., 1999, 2003, 2004; Dyhr et al., 2004; Reis Miranda et al., 2004; Almarakbi et al., 2009; Böhm et al., 2009) and dogs (Staffieri et al., 2010; Canfrán et al., 2012).

However, the application of high intrathoracic pressure can have adverse effects and barotrauma and haemodynamic impairment can result from RMs (Blanch and Villagrá, 2004; Ochagavia et al., 2009). The cardiovascular consequences of RMs have been attributed to increased intrathoracic and transpulmonary pressures, which cause a decrease in venous return and cardiac preload (Nielsen et al., 2005, 2006) and an increase in right ventricular afterload, by increasing pulmonary vascular resistance (Nielsen et al., 2006; Gernoth et al., 2009; Iannuzzi et al., 2010). Both mechanisms decrease right ventricular outflow; thus, left ventricular filling and CO are reduced (Permutt et al., 1962; Pinsky, 1997; Jardin and Vieillard-Baron, 2003).

Several studies have reported the cardiovascular side effects of RMs in both human clinical settings (Grasso et al., 2002; Jardin and Vieillard-Baron, 2003; Nielsen et al., 2005; Toth et al., 2007; Iannuzzi et al., 2010; Monge García et al., 2012) and in experimental settings where pigs were used as experimental models (Lim et al., 2004; Odenstedt et al., 2005a,b; Nielsen et al., 2006). Reductions in cardiac output (CO) and arterial pressure have been demonstrated in both sustained inflation and stepwise manoeuvres in humans and in porcine models and it has been shown that stepwise manoeuvres reduce CO less than sustained inflation manoeuvres (Odenstedt et al., 2005b; Celebi et al., 2007; Iannuzzi et al., 2010). Adequate volemia is also an important factor which can reduce haemodynamic impairment when RMs are applied in porcine models (Odenstedt et al., 2005a; Nielsen et al., 2006).

* Corresponding author. Tel.: +34 9139 43817.
E-mail address: scanfran@vet.ucm.es (S. Canfrán).

1090-0233/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tvjl.2013.05.013

The negative haemodynamic effects of RM have not yet been determined in dogs and could have clinical relevance. Additionally, the utility of fluid therapy to optimise volemia before a RM to prevent or limit such changes is also of clinical interest. Therefore, this study aimed to evaluate the effects of a stepwise RM on the haemodynamics of healthy dogs undergoing general anaesthesia with isoflurane and to determine whether a previous fluid load might prevent or minimize these effects.

Materials and methods

Animals

Institutional Animal Care and Use Committee approval was granted on 1st December, 2011 and Beagle dogs were used. Food and water were withheld from all dogs 12 h prior to experimentation. Animals were determined to be healthy prior to the experiments using haematology and serum biochemistry tests, chest radiographs and echocardiographic examination.

Study design

Using a prospective study design, dogs were anaesthetised for CO measurements during a stepwise lung RM, with and without previous fluid administration. Each dog was anaesthetised once. General anaesthesia was induced 45 min after premedication. A Swan-Ganz catheter was placed in the pulmonary artery to measure CO by the thermodilution method. After catheter placement, dogs were mechanically ventilated (baseline ventilation) until they were normocapnic (end tidal CO_2 35–45 mmHg). The first RM was performed over 7 min and without a previous bolus of fluids (pre-fluid load). After the first RM, there was a 30 min period of baseline ventilation. A fluid load of 10 mL/kg was then administered within 10 min, and the RM was repeated immediately after the fluid load (post-fluid load).

Anaesthesia, instrumentation and RM

All dogs were premedicated with dexmedetomidine (Dexdomitor, Pfizer; 0.005 mg/kg IM) and methadone (Metasedin, Esteve; 0.3 mg/kg IM). After 15 min, a 20-G catheter was placed in the right cephalic vein and the surgical fields (right jugular vein and right metatarsal artery) were shaved. General anaesthesia was then induced with propofol (Propofol Lipuro 1%, B. Braun VetCare; 3–6 mg/kg IV, dose to effect).

All dogs received fluid therapy with lactated Ringer's solution (5 mL/kg/h IV) using an infusion pump (Infusomat, B. Braun) immediately after the induction of anaesthesia. After intubation with a cuffed tube, all dogs were connected to an anaesthetic machine with a mechanical ventilator (Julian Anaesthetic Workstation, Dräger), and were positioned in dorsal recumbency. General anaesthesia was maintained with isoflurane (Isoflo, Esteve; end tidal concentration 1.3–1.5%) and dogs breathed without assistance until the Swan-Ganz thermodilution catheter placement was completed.

A 5-French Swan-Ganz thermodilution catheter (Swan-Ganz TD, 5F; Edwards Lifesciences) was inserted into the right jugular vein via an introducer (Intro-Flex; Edwards Life Sciences), and the distal port of the catheter was positioned in the pulmonary artery. The proximal and distal ports of the catheter were connected to blood pressure transducers (Transpac IV, Hospira), previously set to zero at the level of the heart base. Waveforms from the blood pressure tracers and a fluoroscope (BV 25 Gold C-Arm, Philips) were used to aid the positioning of the Swan-Ganz catheter. The catheter was connected to a CO monitor (SAT-2 Oximeter/Cardiac Output Computer, Baxter).

After the Swan-Ganz catheter was placed, all dogs received vecuronium (Norcuron, MSD; 0.1 mg/kg IV). The dogs were then mechanically ventilated in a volume-controlled mode (baseline mechanical ventilation) with a tidal volume (VT) of 10 mL/kg, a PEEP of 0 cm H_2O, an inspiratory to expiratory ratio of 1:2, and a fraction of inspired oxygen (FiO_2) of 0.4. Respiratory rate was adjusted to maintain an end tidal CO_2 between 35 and 45 mmHg (baseline mechanical ventilation).

Once the end tidal CO_2 was stabilised, a RM was performed (Canfrán et al., 2012). First, the ventilatory mode was changed to a pressure-controlled mode, with a PEEP of 0 cm H_2O and an EIP of 10 cm H_2O. Then, the PEEP and EIP were both increased by 5 cm H_2O increments at 1 min intervals until a PEEP of 15 cm H_2O was reached (after 3 min). The PEEP was then maintained at 15 cm H_2O and EIP was increased to 30 cm H_2O. Afterwards, a VT of 10 mL/kg was applied in a volume-controlled mode, and the PEEP was reduced to 10, 5 and 0 cm H_2O in further 1 min intervals. After the first RM, dogs were mechanically ventilated at baseline as described above for 30 min. An IV bolus of lactated Ringer's solution (10 mL/kg) was administered over 10 min using an infusion pump (Infusomat, B. Braun). Immediately after the administration of the bolus, a second RM was performed using the same procedure. Once the RM was completed, the dogs were returned to unassisted breathing during recovery from anaesthesia.

Monitoring and data collection

CO was monitored during unassisted breathing just after instrumentation, at baseline mechanical ventilation before each RM was started, before the fluid bolus, and at each pressure step in each RM (18 measurements in total). Three millilitres of iced saline solution (0.9% NaCl, 4 °C) were injected over 1–2 s into the proximal port of the Swan-Ganz catheter for each CO measurement. Each injection was performed at end-expiration to maintain consistency. The results of CO from the first injection of saline were discarded from the analysis to avoid bias due to warming of the saline solution. The CO was calculated from the average value of three consecutive injections providing artefact-free thermodilution curves.

The heart rate (HR), as well as systolic arterial pressure, mean arterial pressure (MAP) and diastolic arterial pressure, were measured directly at the metatarsal artery. The respiratory rate, blood oxygen saturation (by pulse oximetry), oesophageal temperature and end tidal carbon dioxide partial pressure ($EtCO_2$) were continuously monitored and recorded at the same time points defined for the CO measurements (PM8060 Vitara Monitor, in Julian Anaesthetic Workstation, Dräger). Systemic vascular resistance (SVR) was also calculated at these time points using the formula

$$SVR = 80(MAP - CVP\ [\text{central venous pressure}])/CO$$

Lung mechanics were monitored at each time point by recording VT, airway pressures (PEEP and peak or plateau pressures) and dynamic compliance (Cdyn). Gas flow was measured through a hot wire anemometry system; VT was recorded by numerical integration of the flow signal, and airway pressures were measured with a piezoresistive transducer. Each of these monitors was integrated into the anaesthetic machine (Julian Anaesthetic Workstation, Dräger). Cdyn was employed to evaluate lung mechanics, ensuring that pulmonary conditions were similar before each RM.

Arterial blood samples were anaerobically collected via indwelling arterial catheters before each RM, and were immediately analysed for partial pressures of arterial oxygen (PaO_2) and carbon dioxide (ABL80 Flex, Radiometer). The values were corrected for body temperature, and PaO_2/FiO_2 was calculated. A PaO_2/FiO_2 > 300 - mmHg was set as the cut point to exclude the existence of major respiratory disease such as acute lung injury or acute respiratory distress syndrome (Bernard et al., 1994; Wilkins et al., 2007).

Statistical analysis

Data were expressed as means ± standard deviation. The sample size calculation was based on a similar study where pigs were subjected to RMs with a PEEP value of 15 cm H_2O and a reduction in CO of 30% (Odenstedt et al., 2005b). These data indicated that the difference in the response of matched pairs was normally distributed with a standard deviation 0.1. If the true difference in the mean response of matched pairs to be detected was 0.15 (15%), at least seven pairs of subjects were required for the null hypothesis to be rejected, with a probability (power) of 0.9. The probability of type I error associated with this test of the null hypothesis was 0.05. From the power calculations, eight animals were enrolled in the study.

Once the normality of the data was assessed using the Kolmogorov–Smirnoff test, Student's *t* test was used for between group comparisons at each time point. A one-way, repeated measures ANOVA was used to determine differences within each group, and the Bonferroni post hoc test was applied. Potential correlations between quantitative data were investigated using Pearson's correlation test. A $P < 0.05$ was considered statistically significant. All statistical analyses were performed using SPSS for Windows (IBM SPSS Statistics release 19).

Results

Animals

The dogs weighed 12.2 ± 1.7 kg and were 2.2 ± 0.4 years old. None of the dogs were removed from the study.

Blood gas analysis and lung mechanics

The PaO_2/FiO_2 ratio was >300 mmHg in all dogs at all time points. The PaO_2/FiO_2 ratio was 464 ± 50 mmHg prior to the first RM and 511 ± 44 mmHg prior to the second RM. These values were not significantly different ($P = 0.089$).

The Cdyn increased significantly after the RM in both groups (repeated measures analysis, $P < 0.05$). Cdyn values before each RM were similar in both groups, and differences were not statistically significant ($P = 0.15$).