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CASE REPORT

Variety of non-invasive continuous monitoring methodologies including electrical impedance tomography provides novel insights into the physiology of lung collapse and recruitment – case report of an anaesthetized horse

Yves Moens*, Johannes P Schramel*, Gerardo Tusman†, Tamas D Ambrisko*, Josep Solà‡, Josef X Brunner§, Lidia Kowalczyk* & Stephan H Böhm§

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

†Department of Anaesthesiology, Hospital privado de Comunidad, Mar del Plata, Argentina

‡CSEM Centre Suisse d'Electronique et de Microtechnique SA, Neuchâtel, Switzerland

§Swisstom AG, Landquart, Switzerland

Correspondence: Yves Moens, Anaesthesiology and perioperative Intensive-Care, University of Veterinary Medicine, Veterinaerplatz 1, 1210 Vienna, Austria. E-mail: yves.moens@vetmeduni.ac.at

Abstract

Introduction The use of alveolar recruitment maneuvers during general anaesthesia of horses is a potentially useful therapeutic option for the ventilatory management. While the routine application of recruitments would benefit from the availability of dedicated large animal ventilators their impact on ventilation and perfusion in the horse is not yet well documented nor completely understood.

Case history A healthy 533 kg experimental horse underwent general anaesthesia in lateral recumbency. During intermittent positive pressure ventilation a stepwise alveolar recruitment maneuver was performed.

Management Anaesthesia was induced with ketamine and midazolam and maintained with isoflurane in oxygen using a large animal circle system. Mechanical ventilation was applied in pressure ventilation mode and an alveolar recruitment maneuver performed employing a sequence of ascending and descending positive end expiratory pressures. Next to the standard monitoring, which included spirometry, additionally three non-invasive monitoring techniques were used: electrical impedance tomography (EIT), volumetric capnography and respiratory ultrasonic plethysmography. The functional images continuously delivered by EIT initially showed markedly reduced ventilation in the dependent lung and allowed on-line monitoring of the dynamic changes in the distribution of ventilation during the recruitment maneuver. Furthermore, continuous monitoring of compliance, dead space fraction, tidal volumes and changes in end expiratory lung volume were possible without technical difficulties.

Follow up The horse made an unremarkable recovery.

Conclusion The novel non-invasive monitoring technologies used in this study provided unprecedented insights into the physiology of lung collapse and recruitment. The synergic information of these techniques holds promise to be useful when developing and evaluating new ventilatory strategies in horses.

Keywords capnography, compliance, electrical impedance tomography (EIT), horse, lungs, non-invasive monitoring, positive end expiratory pressure (PEEP), recruitment maneuver.

Introduction

It is well recognized that large (A-a) PO_2 differences can develop during equine anaesthesia. As a consequence hypoxemia is reported regularly even during elective procedures in healthy horses (Hall et al. 1968; Day et al. 1995). It is also generally accepted that this potentially life-threatening disturbance of lung function with pronounced V/Q mismatching is caused mainly by atelectasis formation in dependent lung regions and concomitant right-to-left intrapulmonary shunting (Nyman et al. 1990). While intermittent positive pressure ventilation (IPPV) can correct hypoventilation and the elevated arterial carbon dioxide levels seen during anaesthesia, its effect on improving oxygenation is usually disappointing. Unfortunately, such lack of effect is also witnessed often when positive end-expiratory pressure (PEEP) is used in an attempt to treat hypoxemia.

New ventilatory strategies based on the 'Open Lung Concept' of Lachmann (Intensive Care Med, 1992) – now commonplace in human medicine (Tusman & Belda 2010; Tusman & Böhm 2010) – are currently being explored successfully in horses (Levionnois et al. 2006; Schürmann et al. 2008; Bringewatt et al. 2011; Hopster et al. 2011; Moens & Böhm, 2011; Staffieri et al. 2011). Searching the abundant human and the scarce veterinary literature for reference values to be used during lung recruitment in horses, it can be argued that the airway pressures commonly applied in horses during IPPV with and without PEEP are usually insufficient to re-expand anaesthesia-induced atelectasis. In large horses it is expected that the large superimposed gravitational gradient within the lung tissue requires recruitment pressures in excess of the 40, 50 and 60 cmH_2O, the minimum plateau pressures typically employed in healthy, obese and morbidly obese humans, respectively (Böhm et al. 2009a,b; Tusman & Belda 2010). Thus, to open collapsed alveoli, and to keep them open, peak inspiratory pressures (PIP) of up to 80 cmH_2O and PEEPs up to 25 cmH_2O seem to be justified at least in some horses (Schürmann et al. 2008; Bringewatt et al. 2011; Hopster et al. 2011). However, these high airway pressures inevitably induce cardiovascular and pulmonary side effects such as decreases in cardiac output and blood pressure as well as overdistension of lung parenchyma which result in augmented dead space fractions (Wettstein et al. 2006; Böhm et al. 2009a). Therefore, the concept of 'best or open lung PEEP', defined as the lowest PEEP in an individual patient that keeps alveoli open without overdistending them, was proposed by Suarez-Sipmann et al. (2007) and later confirmed (Tusman & Belda 2010; Tusman & Böhm 2010). It is highly likely that this fundamental physiological concept is also applicable for the management of equine ventilation (Moens & Böhm 2011). However, to implement this ventilation strategy in clinical practice appropriate monitoring tools are needed to guide therapy.

This case report aims to document by a variety of continuous non-invasive monitoring means (1) the physiological effects of stepwise PEEP titrations and (2) the opening and the closing of alveoli in an anaesthetized and mechanically ventilated horse in lateral recumbency. The recruitment intervention was also recorded by electrical impedance tomography (EIT), a novel imaging technology capable of displaying changes in regional lung aeration during a tidal breathing cycle and of visualising the impact of mechanical ventilation separately for each lung. Additional monitoring consisted of electronic spirometry, volumetric capnography and respiratory ultrasonic plethysmography (RUP). To the best of the authors' knowledge a recruitment manoeuvre has never before been documented with this unique set of non-invasive monitoring techniques and should therefore provide novel insights into the regional distribution of alveolar collapse and recruitment.

Case history and methods

The procedure was approved by the Institutional Ethics Committee and the National Authority according to the Law for Animal Experiments (BMWF-68.205/0059-II/3b/2011). The subject was a 533 kg warm blood horse owned by the University and free of clinically apparent lung disease. Following premedication and induction of anaesthesia with intravenous ketamine and midazolam, the horse was connected to an anaesthetic circle system. Anaesthesia was maintained with isoflurane in oxygen (inspired oxygen fraction ≥ 0.90) and a continuous rate intravenous infusion of a mixture of ketamine, xylazine and midazolam. The horse was positioned in right lateral recumbency.

Clinical monitoring consisted of the continuous recording of electrocardiogram, heart rate, respiratory gas composition, arterial oxygen saturation and invasive blood pressure. Arterial blood was sampled for blood gas analysis (arterial partial pressures of oxygen (PaO_2) and carbon dioxide ($PaCO_2$) and pH)