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RESEARCH PAPER

Measurement of tidal volume using Respiratory Ultrasonic Plethysmography in anaesthetized, mechanically ventilated horses

Elena Russold*, Tamas D Ambrisko*, Johannes P Schramel*, Ulrike Auer*, Rene Van Den Hoven† & Yves P Moens*

*Anaesthesiology and Perioperative Intensive Care – Medicine, Department of Companion Animals and Horses, University of Veterinary Medicine, Vienna, Austria

†Equine Internal Medicine, Department of Companion Animals and Horses, University of Veterinary Medicine, Vienna, Austria

Correspondence: Elena Russold, Anaesthesiology and Perioperative Intensive Care-Medicine, Department of Companion Animals and Horses, University of Veterinary Medicine, Veterinärplatz 1, 1210 Vienna, Austria. E-mail: elena.russold@vetmeduni.ac.at

Abstract

Objective To compare tidal volume estimations obtained from Respiratory Ultrasonic Plethysmography (RUP) with simultaneous spirometric measurements in anaesthetized, mechanically ventilated horses.

Study design Prospective randomized experimental study.

Animals Five experimental horses.

Methods Five horses were anaesthetized twice (1 week apart) in random order in lateral and in dorsal recumbency. Nine ventilation modes (treatments) were scheduled in random order (each lasting 4 minutes) applying combinations of different tidal volumes (8, 10, 12 mL kg^{-1}) and positive end-expiratory pressures (PEEP) (0, 10, 20 cm H_2O). Baseline ventilation mode (tidal volume = 15 mL kg^{-1}, PEEP = 0 cm H_2O) was applied for 4 minutes between all treatments. Spirometry and RUP data were downloaded to personal computers. Linear regression analyses (RUP *versus* spirometric tidal volume) were performed using different subsets of data. Additonally RUP was calibrated against spirometry using a regression equation for all RUP signal values (thoracic, abdominal and combined) with all data collectively and also by an individually determined best regression equation (highest R^2) for each experiment (horse *versus* recumbency) separately. Agreement between methods was assessed with Bland-Altman analyses.

Results The highest correlation of RUP and spirometric tidal volume ($R^2 = 0.81$) was found with the combined RUP signal in horses in lateral recumbency and ventilated without PEEP. The bias ± 2 SD was 0 ± 2.66 L when RUP was calibrated for collective data, but decreased to 0 ± 0.87 L when RUP was calibrated with individual data.

Conclusions and clinical relevance A possible use of RUP for tidal volume measurement during IPPV needs individual calibration to obtain limits of agreement within ± 20%.

Keywords anaesthesia, horse, mechanical ventilation, monitoring, respiratory ultrasonic plethysmography, tidal volume.

Introduction

Hypoventilation is a common side effect of general anaesthesia in horses. Recumbency and anaesthetic drugs often cause a decrease in tidal volume and respiratory rate (Robinson 2009). Mechanical ventilation with or without positive end-expiratory pressure (PEEP) may be necessary during anaesthesia to correct hypoventilation and improve gas exchange. The choice of appropriate settings for mechanical ventilation is, amongst other factors, facilitated by the measurement of tidal volume and respiratory rate. Pitot tube based spirometry at the level of the endotracheal tube is a practical method to perform this measurement during routine clinical anaesthesia in horses (Moens et al. 2009). An alternative completely non-invasive approach for estimating tidal volume and respiratory rate uses the measurement of thoracic and abdominal excursions following volume changes of the lungs during spontaneous and mechanical ventilation. Respiratory Inductive Plethysmography (RIP) is based on this principle and is an established method to monitor respiration in infants (Warren & Alderson 1986) but it is also used in standing horses (Amory et al. 1994; Miller et al. 2000; Hoffman et al. 2001, 2007). The RIP technique is based on measurement of changes of a cross-sectional area. Electrical coils embedded in belts are placed around the thorax and abdomen and changes in circumference are translated into changes of electric inductance, which are then recorded. If simultaneously, respiratory volumes are measured by another method, this signal can be calibrated for respiratory volumes (Cohn et al. 1982; Tobin et al. 1983; Brown et al. 1998). Respiratory ultrasonic plethysmography (RUP) is a new technology which allows measurement of the changes of thoracic and abdominal circumferences based on the measurement of sound velocity through fluid filled tubes (Schramel 2008; Schramel et al. 2012).

The aims of this study were to evaluate the relationship of RUP output data and spirometric tidal volume measurements in horses under general anaesthesia undergoing intermittent positive pressure ventilation (IPPV).

Materials and methods

The study was discussed and approved by the institutional ethical committee and the Austrian Federal Ministry of Science and Research (TVG Nr 68205/171-II/106/2008). Eight horses were enrolled in the study, being (mean ± SD) 9.8 ± 11.7 years old and weighing 517 ± 68.5 kg. The animals were considered healthy based on clinical examination, routine haematological and biochemical blood testing and lung function testing prior to the study. The data of the first three horses were excluded from analysis because a modification of the characteristics of the reference (baseline) ventilatory modus was necessary to avoid interference from occasional spontaneous respiratory efforts during IPPV. The remaining five horses were 13 ± 6 years old and weighed 531 ± 77 kg. Each horse was anaesthetized twice, once in dorsal and once in left lateral recumbency in random order and with a 1 week interval between anaesthetics.

Anaesthesia and instrumentation

Prior to anaesthesia, the animals were starved for 12 hours, but allowed free access to water. A 12 gauge intravenous (IV) catheter was placed in the jugular vein and the horses were sedated with 0.02 mg kg^{-1} acepromazine IV. About 20 minutes later, the animals received 0.75 mg kg^{-1} xylazine and 0.025 mg kg^{-1} butorphanol IV, followed 5 minutes later by induction of anaesthesia with 2.2 mg kg^{-1} ketamine and 0.1 mg kg^{-1} diazepam. After the horses became recumbent, the trachea was intubated (inner diameter 30 mm) and the animal was hoisted and positioned on the table. The endotracheal tube was connected to a large animal circle breathing system and mechanical ventilation was started immediately using 15 mL kg^{-1} tidal volume and 0 cm H_2O PEEP (L.A. 95 – Smith ventilator; HSH Anaesthetic Equipment, Denmark). Anaesthesia was maintained with isoflurane in oxygen. Additionally, a constant rate infusion of ketamine (6 mg kg^{-1} $hour^{-1}$), xylazine (0.3 mg kg^{-1} $hour^{-1}$) and midazolam (18 μg kg^{-1} $hour^{-1}$) was administered throughout the anaesthetic period. The animals received 0.9% NaCl solution at 7–10 mL kg^{-1} $hour^{-1}$ IV. Physiological parameters were monitored using ECG, pulse oximetry, capnography and a direct arterial blood pressure monitoring system (Datex-Ohmeda S/5 Monitor; Planar Systems Inc., USA). Spirometry was performed with a mainstream sensor (Horse-Lite; Morpheus Engineering, Netherlands) attached between the endotracheal tube and the circle breathing system and connected to the Datex-Ohmeda S/5 Monitor. The RUP sensors, two ethanol filled rubber tubes with ultrasonic transducers at one end, were placed around the thorax (11th intercostal space) and around the abdomen (caudal of the last rib) and connected to a personal computer. Arterial blood was taken every 15 minutes, and analysed for pH and blood gases. Animals