Effect of position on transdiaphragmatic pressure and hemodynamic variables in anesthetized horses

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Abstract

Recumbency affects respiratory mechanics and oxygenation in anesthetized horses. Changes in pleural and abdominal pressures that can impair ventilation have not been described in all recumbencies. The objective of this study was to determine the effects of patient positioning on transdiaphragmatic pressures and selected hemodynamic variables. Horses were maintained under total intravenous general anesthesia with nasal oxygen supplementation. Trans-nasal balloon catheters connected to pressure transducers placed within the stomach and thoracic esophagus were used to measure intrathoracic and gastric pressure in standing and anesthetized horses positioned in: right and left lateral recumbency, dorsal recumbency, reverse Trendelenburg position, and Trendelenburg position. Transdiaphragmatic pressures were calculated as the difference between gastric and intrathoracic pressure. Measurements of SpO_2, heart rate, systolic, diastolic and mean arterial pressure, and respiratory rate were obtained every 5 minutes. When compared to dorsal recumbency, gastric expiratory pressure is decreased in the standing position. Thoracic expiratory pressure is decreased in standing and reverse Trendelenburg. Transdiaphragmatic expiratory pressure and SpO_2 are decreased in Trendelenburg. Heart rate is increased in reverse Trendelenburg. Systolic, diastolic, and mean arterial pressures are decreased in reverse Trendelenburg and increased in left lateral and right lateral. We found there is wide variation in respiratory pressures between horses and positions and they are not predictive of associated changes in hemodynamic variables.

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Chapter 1 - Introduction

Large differences in arterial and alveolar oxygen tensions have been demonstrated in recumbent horses due to ventilation perfusion mismatch (1–4). A major source of this ventilation perfusion mismatch is the development of atelectasis and decreased functional residual capacity (1,2,5–7). A cephalad shift of the diaphragm occurs during recumbency secondary to pressure from the abdominal contents and has been implicated in the development of atelectasis in the dependent lung (7,8). The transmission of intra-abdominal pressure to the thoracic cavity has been demonstrated to impair respiratory mechanics in multiple species (9–11). Intra-abdominal pressure has also been shown to change with patient positioning, body mass, disease processes, and surgical technique (12–16).

Placing patients in a reverse Trendelenburg position has been used in humans and horses successfully in an attempt to improve ventilation by decreasing the pressure placed on the pleural cavity and lungs by the abdominal cavity (17–19). Alternatively, Trendelenburg position is utilized in some equine surgical procedures such as urogenital laparoscopy. Placing horses in this position with abdominal insufflation results in decreased PaO_2 and pH as well as increased $PaCO_2$ and mean arterial pressure by increasing the pressure transmission from the abdomen (20).

Transdiaphragmatic pressure, or the difference between abdominal and pleural pressure, is commonly used to evaluate diaphragmatic contractility and work of breathing and has been evaluated in laterally recumbent and exercising horses (21,22). However, these values have not been evaluated together in horses in different recumbencies. Therefore, the purpose of this study was to establish baseline pleural and abdominal pressures and subsequently transdiaphragmatic pressure in various recumbent positions to better understand the effects of patient positioning.

Chapter 2 - Materials and Methods

Animals

Ten horses free of cardiopulmonary disease were used for a randomized crossover study. The experimental protocol was approved by the Kansas State University Institutional Animal Care and Use Committee.

Instrumentation

A 14 ga IV catheter was placed in the left jugular vein. Horses were sedated with xylazine (Anased LA, MWI Animal Health, 3041 West Pasadena Drive, Boise, Idaho 83705)(0.4 mg/kg, IV). Two custom made balloon catheters were fastened together with the balloons 40cm apart as previously described for standardization (21). Balloons were filled with 5 ml of air. The catheters were placed transnasally such that one balloon was within the gastric lumen and the other was within the thoracic esophagus caudal to the heart. Placement of the catheters was confirmed by observation of characteristic pressure changes with the respiratory cycle using aneroid manometers. Catheters were connected to a differential pressure transducer (Omega PX26-005 DV, Omega Engineering, Inc., One Omega Drive, P.O. Box 4047, CT 06907-0047)[b] coupled two to stages of amplification. The amplified signal was digitized and logged to a computer using the NI myDAQ platform and LabVIEW software (National Instruments,11500 N Mopac Expwy, Austin, TX 78759-3504).

Anesthesia

General anesthesia was induced with xylazine (1.1 mg/kg, IV), ketamine (Ketaset, Zoetis, 10 Sylvan Way, Parsippany, New Jersey 07054) (2.2 mg/kg, IV) and midazolam (Akorn, Inc.

1925 West Field Court, Suite 300 Lake Forest, Illinois 60045) (0.05 mg/kg, IV). Horses were maintained on a constant rate infusion of GKX (guaifenesin (Medisca, 6641 North Belt Line Road, Unit 130, Irving, TX 75063 USA) 50g/L, ketamine 4.4 mg/kg/L, xylazine 1.1mg/kg/L) at 1 L/hr. Horses were supplemented with nasal insufflation of oxygen at 15 liters/ minute. Instrumentation was performed with the horses positioned on a surgery table in dorsal recumbency. Horses were instrumented with a facial arterial catheter for continuous arterial pressure monitoring with the pressure transducer placed at the level of the right atrium, base apex ECG leads, and lingual pulse oximetry. Once horses were instrumented, body position was changed based on random assignment.

Data Collection

Measurements of intrathoracic and gastric pressure were made with the horses standing, and in anesthetized horses positioned in left lateral recumbency, right lateral recumbency, dorsal recumbency, dorsal recumbency with the table tilted head down 15^0, and dorsal recumbency with the table tilted head up 15^0. The order was determined by random assignment. Two minutes elapsed following repositioning before measurements were made in each position.

Three consecutive breaths were chosen from a time pressure waveform that represented the normal breathing pattern in each position, excluding breath holds or sighs (Figure 1). Peak inspiratory and expiratory pressures were measured from the gastric and intrathoracic waveform for the three breaths. Values were averaged to determine mean intrathoracic inspiratory, intrathoracic expiratory, gastric inspiratory, and gastric expiratory pressure. Transdiaphragmatic pressures were calculated for inspiration and expiration as the difference between mean gastric and mean intrathoracic pressure. Measurements of SpO_2, heart rate, systolic, diastolic and mean pressure, and respiratory rate were measured every 5 minutes after induction of general anesthesia.

Data analysis

Respiratory pressures and hemodynamic variables were analyzed by a mixed linear regression model. Effect of position on respiratory pressures and hemodynamic variables, and effect of respiratory pressures on hemodynamic variables was determined with a Wald test. Level of significance was set at P< 0.05.

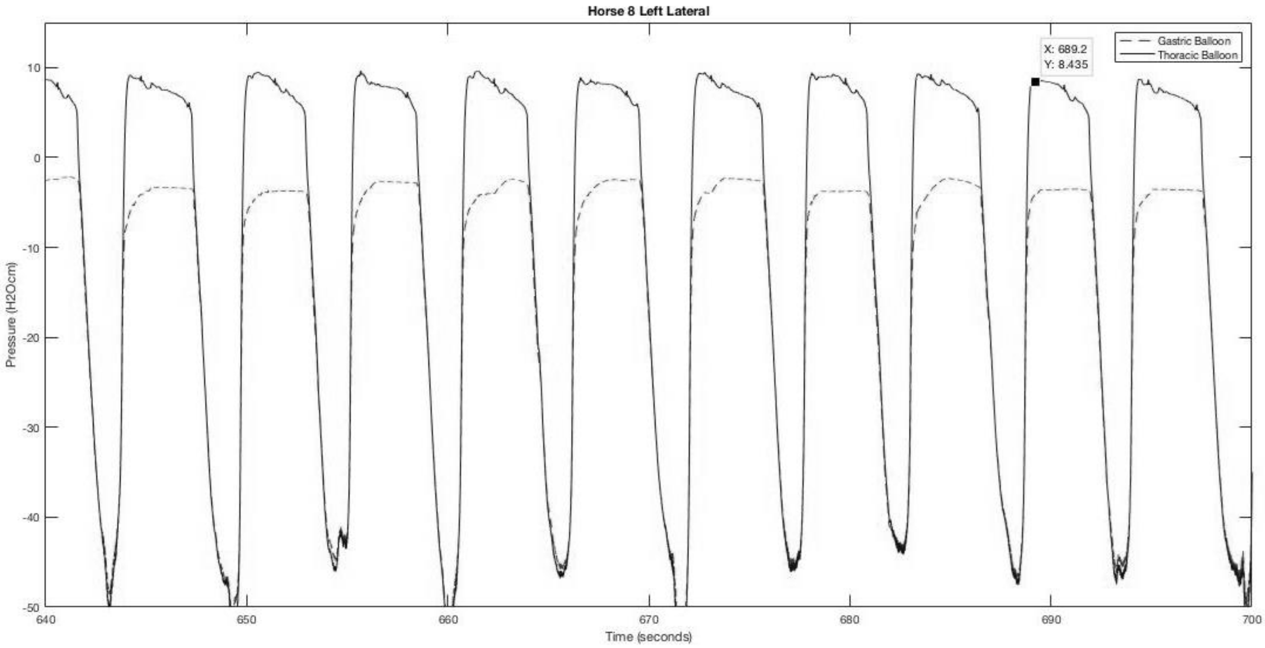

Figure 1 Pressure in centimeters of water was graphed over time for the gastric (dashed line) and thoracic (solid line) balloons. Peak inspiratory and expiratory pressures for each balloon were identified for three consecutive breaths and averaged.

Chapter 3 - Results

Animals

Ten horses were included in the analysis including three mares, six geldings, and one stallion. There were eight Quarter Horses, one Tennessee Walker, and one Thoroughbred. Age ranged from 4 to 25 years (mean 13.4 years). Weight ranged from 425 to 580 kg (mean 496.4 kg).

Effect of position on respiratory pressures and hemodynamic variables

Hemodynamic variables and respiratory pressures are reported as means and 95% confidence interval by position (Figures 2 and 3). When position was found to be a significant factor, each position was compared to dorsal recumbency as the reference position. In reverse Trendelenburg, thoracic expiratory pressure and systolic, diastolic, and mean arterial pressures were decreased and heart rate was increased. In Trendelenburg position, transdiaphragmatic expiratory pressure and SpO_2 were decreased. Systolic, diastolic and mean arterial pressures were increased in left and right lateral recumbencies. In a standing position gastric and thoracic expiratory pressure was decreased. Position did not significantly impact gastric, thoracic, or transdiaphragmatic inspiratory pressure or respiratory rate.

Effect of respiratory pressures on hemodynamic variables

SpO_2 was positively correlated with gastric and transdiaphragmatic inspiratory pressure. Systolic arterial pressure was positively correlated with gastric and thoracic expiratory pressure. Respiratory rate was negatively correlated with expiratory transdiaphragmatic pressure.

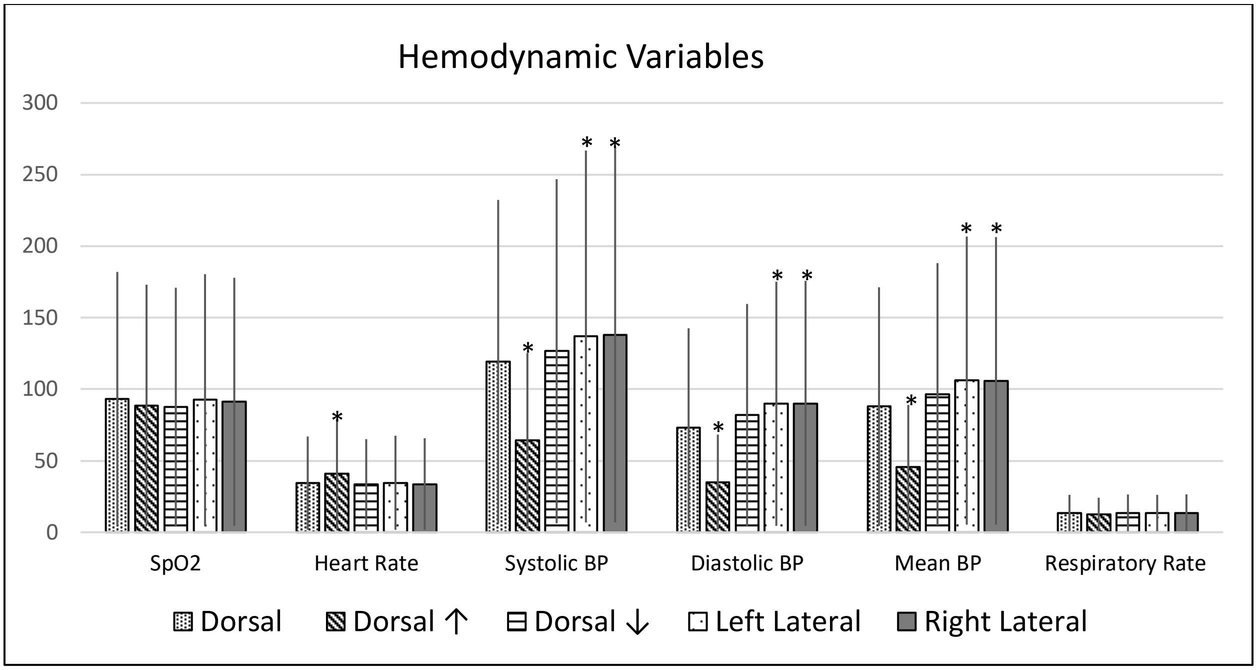

Figure 2 Mean +/- 95% confidence interval values for SpO2 in %, heart rate in beats per minute, arterial blood pressure in mmHg, and respiratory rate in breaths per minute are reported by position. Values significantly different from dorsal recumbency are designated with an asterisk.

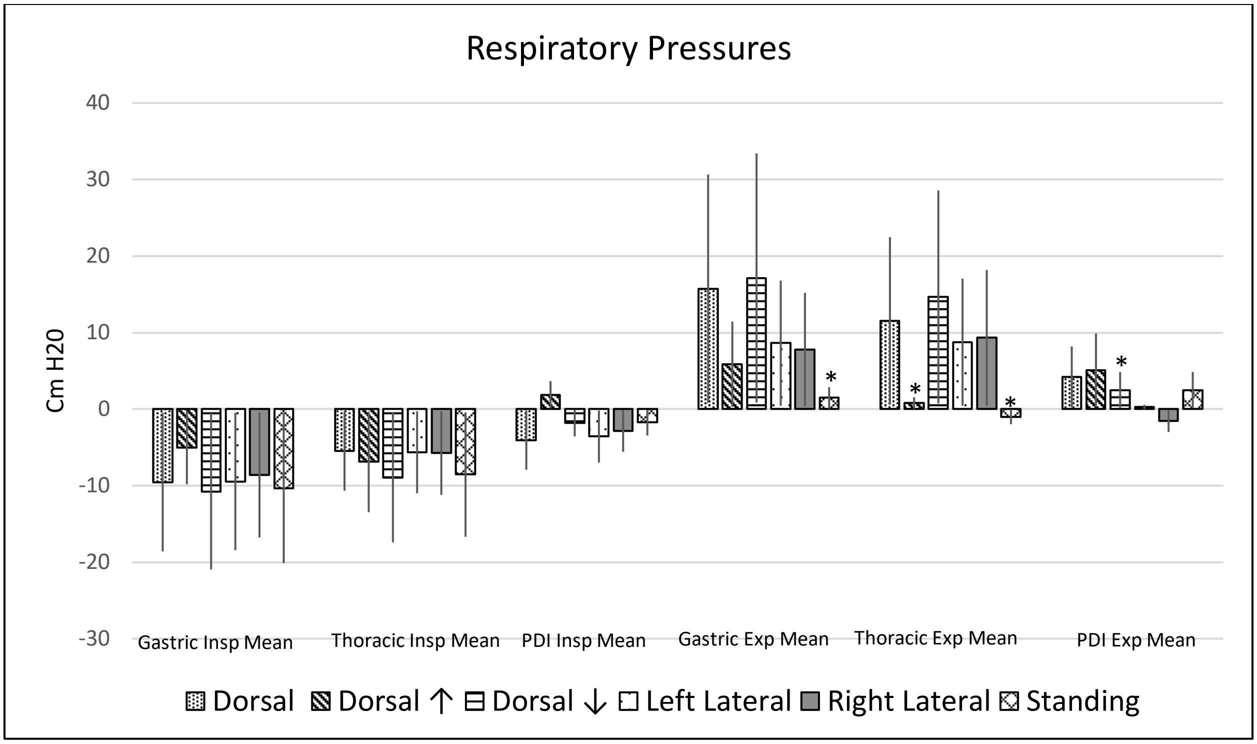

Figure 3 Mean +/- 95% confidence interval values for gastric, thoracic, and transdiaphragmatic (PDI) pressures in CmH20 for both inspiration and expiration are reported by position. Values significantly different from dorsal recumbency are designated with an asterisk.

Chapter 4 - Discussion

Changes in gastric and thoracic respiratory pressures with change in position were variable between horses, but followed an expected pattern. For the majority of horses and positions, gastric and thoracic inspiratory pressures tended to be negative, or subatmospheric, and expiratory pressures tended to be positive. Transdiaphragmatic pressures, however, did not display a trend among horses or position and seemed to be more variable in both the magnitude and direction of deflection.

Pleural, abdominal, and transdiaphragmatic pressures can be used to measure compliance, energy expenditure of breathing, and respiratory muscle function (22,23). Distending pressure of the lung is the difference between atmospheric pressure and pleural pressure and determines the lung volume and ventilation (23). The distending pressure is impacted by pressure from the abdominal viscera on the diaphragm (23). In this study our interest was in establishing normal measurements of the relative pressure being placed across the diaphragm in horses that could be used to illuminate the effect of patient positioning on the distending pressure of the lung and not necessarily the work of breathing. The increase in gastric and thoracic expiratory pressures seen in recumbency compared to standing may be responsible for the decrease in functional residual capacity and airway closure that has been reported in recumbent horses (2,6,7). The decrease in thoracic expiratory pressure in reverse Trendelnburg position would theoretically reduce airway closure. It is possible this is responsible for the improvement in oxygenation seen in horses and humans in this position in previous studies, however no benefit was seen in SpO_2 in the current study (18,19,24). This could be due to a lack of mechanical ventilation, lower inspired oxygen concentration, and relatively short time interval that horses were in this position during this study. An absence of benefit seen in our study with this position could also be a consequence of random position assignment, as Binetti showed that RT was able to prevent but not reverse gas exchange impairment from atelectasis formation (18).

Changes in respiratory pressures were not predictive of the associated hemodynamic changes seen with change in position. This indicates that factors other than respiratory pressures are responsible for hemodynamic changes in different positions. Arterial blood pressure was decreased in the reverse Trendelenburg position similar to the effects of this position seen on cardiovascular parameters in humans, cattle, and swine (25–27). In humans this has been shown to be due to a decrease in preload secondary to blood pooling in the lower extremities (25). Schauvliege et al showed no difference in arterial blood pressure between dorsal and 7^0 reverse Trendelenburg, in fact arterial pressures increased with time in their study. This was likely due to the use of dobutamine, which was also increased over time (19). Lesser degree of table tilt may have also limited blood pooling and adverse cardiovascular side effects seen in our study and in people. In this study we elected a table tilt of 15^0 because the tilt of 30^0 that is often utilized clinically in humans was considered unnecessary for surgical access to the caudal abdomen and decreased tilt in horses and cattle prevented adverse cardiovascular effects (17,18,24,27). The improvement in arterial pressure seen in both lateral recumbencies compared to dorsal is also consistent with previous findings and is likely due to the decreased pressure on the caudal vena cava from the abdominal viscera resulting in an improved preload (28). The decrease in SpO_2 in Trendelenburg is consistent with previous studies and is likely due to the weight of the abdominal viscera on the diaphragm resulting in atelectasis of the caudodorsal lung fields and therefore an increased ventilation/perfusion mismatch (20).

A limitation of this study is the ability of the gastric and esophageal balloons to accurately measure global pleural, abdominal, and transdiaphragmatic pressures in all positions. Previous evaluation of the use of esophageal balloons to estimate pleural pressure show that despite a pleural pressure gradient increasing from dorsal to ventral, balloons in the middle and caudal thoracic esophagus were not significantly different from any of the direct measurements (29). This was evaluated in standing ponies and therefore we do not know if the same accuracy is maintained in different recumbencies in horses (29). Measurement of abdominal pressure differs with measurement location and body position(15,22). The use of gastric balloons for the measurement of intra-abdominal pressure has been shown to be poorly correlated with direct measurement in horses, however direct measurements also differ greatly depending on the location of measurement (15,30,31). Therefore the relative cranial position of the gastric balloon in the abdomen would subject it to forces by the caudal viscera, and may not provide a completely accurate representation of global intra-abdominal pressure as positions are changed. The measure of gastric pressure in the cranial abdomen, however, is likely more applicable to our goal of identifying pressure exerted on the pleural cavity by the abdominal cavity.

In summary inspiratory pressures in horses tend to be subatmospheric and expiratory pressures are more positive. The change in these pressures with changes in position are as one would expect with relative pressure exerted from the abdominal viscera. Transdiaphragmatic pressure does not appear to change as intuitively with position, nor does it predict physiologic changes seen in different positions.

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