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Effect of body position on intra-abdominal pressures and abdominal perfusion pressures measured at three sites in horses anesthetized with short-term total intravenous anesthesia

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Victoria H. Scott, BVetMed, MS; Jarred M. Williams, DVM, PhD: Margaret C. Mudge, VMD; Samuel D. Hurcombe, BVMS, MS

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From the Department of Veterinary Clinical Sciences, College of Veterinary Medicine, The Ohio State University, Columbus, OH 43210. Dr Scott's present address is Department of Veterinary Medicine, University of Cambridge, Madingley Road, Cambridge, England, CB3 0ES.4

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Address correspondence to Dr. Scott (vikki.scott7@gmail.com) 5.

Objective—To assess effects of body position on direct measurements of intra-abdominal pressure (IAP) and abdominal perfusion pressure (APP) in horses anesthetized with total intravenous anesthesia (TIVA).

Animals—9 healthy adult horses.

Procedures—Instrumentation in unsedated standing horses involved insertion of an arterial catheter for blood pressure measurements and 3 intraperitoneal cannulas (left flank, right flank and ventral abdomen) for IAP measurements. Baseline values were measured for heart rate, respiratory rate, systolic arterial pressure, mean arterial blood pressure (MAP), diastolic arterial blood pressure, and IAP. Horses were medicated with xylazine and pressures were measured again. Anesthesia was induced with ketamine-diazepam and maintained with a ketamine-guaifenesin infusion. Horses were positioned twice into left lateral recumbency, right lateral recumbency, or dorsal recumbency. Hemodynamic pressures and accessible abdominal pressures were measured for each recumbency position. The APP was calculated as MAP – IAP. Differences in IAP, MAP, APP and sedation (standing horses) or body position (anesthetized horses) were compared by repeated-measures ANOVA or paired *t* tests.

Results—Baseline hemodynamic and intra-abdominal pressures were not different after xylazine administration. Ventral abdomen IAP and MAP were lower for horses in dorsal recumbency than in right or left lateral recumbency. Ventral abdomen APP remained unchanged. For lateral recumbencies, flank IAP was lower and APP was higher than pressure measurements at the same sites for dorsal recumbency.

Conclusions and Clinical Relevance—Body position affected IAP and APP in healthy anesthetized horses. These effects should be considered when developing IAP acquisition

methods for use in horses with abdominal disease. (*Am J Vet Res* 2014;75:xxx–xxx)

Approximately 250 words **6**

Abbreviations **7**

APP	Abdominal perfusion pressure
CI	Confidence interval
DAP	Diastolic arterial blood pressure
IAH	Intra-abdominal hypertension
IAP	Intra-abdominal pressure
MAP	Mean arterial blood pressure
SAP	Systolic arterial blood pressure
TIVA	Total intravenous anesthesia

Accurate measurement of IAP in human medicine has become an increasingly important monitoring tool for critically ill patients. Intra-abdominal hypertension in humans is defined as sustained IAP ≥ 12 mm Hg.[1] Complications associated with protracted IAH include reduced microcirculatory blood flow to viscera, development of organ dysfunction, and possible organ failure. Abdominal perfusion pressure is a calculated index of abdominal blood flow (MAP –

IAP) and has been proposed as an accurate predictor of visceral perfusion and an end point for resuscitation.[2,3] Abdominal compartment syndrome describes the natural progression of pressure-induced organ changes that develop if IAH is not recognized and treated in a timely manner.[1] In critically ill humans, IAH is a risk factor for organ failure and fatality.[4] Mortality rates associated with abdominal compartment syndrome in critically ill adults and children range from 50% to 60%.[5]

Identification of IAH and abdominal compartment syndrome in any species requires accurate measurement of IAP. In humans, indirectly measured intravesicular pressures are considered accurate and can be used for serial acquisition of IAP.[1] Many variables, including body position, directly affect abdominal pressures.[6–11] Therefore, it is advised that IAP measurements be obtained with the person in supine recumbency.[1,12] Body position can also affect directly measured IAP in dogs anesthetized with short-term TIVA.[13] Standardized methods of IAP measurement in horses and reference range values are lacking. Previous reports[14,15] in horses have indicated that direct intraperitoneal cannulation is the most accurate method, with reduced variation of IAP, compared with results for indirect intravesicular or intragastric techniques. Furthermore, IAP can differ depending on the location in the abdomen of standing horses.[16] To our knowledge, the effect of body position on directly measured abdominal pressure has not been evaluated and must be examined if IAP is to be a potentially useful monitoring tool in critically ill equine patients.

Manipulation of body position in horses requires anesthetic immobilization. Sedation and TIVA are frequently used in horses to facilitate minor procedures performed by practitioners in both field and hospital settings. In humans with IAH, administration of sedatives is a nonsurgical method for lowering IAP through abdominal wall relaxation.[17,18] Investigators in a recent study[16] found that right flank IAP in clinically normal unsedated standing horses was similar to that reported in another study[14] in which horses were sedated by administration of detomidine administered 30 minutes before IAP measurement. This indicated that sedative administration may have negligible effects on IAP in clinically normal horses. Although the effects of sedation and various anesthetic regimens on systemic hemodynamic variables have been characterized in healthy horses,[19–22] IAP and APP in sedated horses and horses anesthetized with TIVA and placed in various body positions are currently unknown.

The purpose of the study reported here was to determine whether body position influences IAP and APP in healthy horses under clinically relevant conditions. Results of the study may be useful in subsequently developing standardized methods for acquisition of IAP measurements that can be applied in both field and hospital settings to horses with abdominal disease. We hypothesized that direct measurement of abdominal pressures (IAP and APP) at 3 sites in healthy standing horses will not be affected by sedation achieved by IV administration of xylazine but that abdominal pressures at the 3 sites will be affected by body position of horses anesthetized with TIVA. Specifically, an increase in IAP and decrease in APP is anticipated whenever the respective site of measurement is closer to the ground, compared with values when the measurement site is farther from the ground.

Materials and Methods

Animals—Nine university-owned adult (> 1 year old) female horses of various breeds were included in the study. Horses were considered free of abdominal disease on the basis that no abnormalities were detected during physical examination and per rectal examination, there was no history of colic or abdominal surgery during the preceding 6 months, and no abnormalities were detected during transabdominal or transthoracic ultrasonography. The animal use protocol and all experimental procedures were approved by the institutional animal care and use committee of The Ohio State University as well as the institutional clinical trials office and hospital clinical research advisory committee. All procedures complied with the National Institutes of Health standards for the ethical treatment of animals.

Instrumentation—In an attempt to standardize the amount of material in the gastrointestinal tract among the study population, 4 L of mineral oil were administered via nasogastric intubation and food was withheld for 24 hours before instrumentation. Water was withheld for 6 hours before instrumentation and any experiments. Horses were housed in temperature-controlled (25°C) indoor stalls. All horses were weighed and assigned a body condition score[23] immediately prior to instrumentation.

Nonsedated horses were placed in a standing position in stocks for instrumentation. Sites for catheter insertion were clipped and aseptically prepared by use of chlorhexidine gluconate and isopropyl alcohol. Local anesthesia was achieved by **SC** injection 8of mepivacaine,[a]9 and a 14-gauge, 5.25-inch catheter[b] was placed in the left jugular vein and secured with 2-0 polypropylene suture[c] to provide venous access in all horses. Local anesthesia was achieved by **SC** injection 8of mepivacaine, and a 20-gauge, 1.25-inch catheter[d] was placed in a transverse facial artery or facial artery for direct measurement of arterial blood pressures (SAP, MAP, and SAP). The arterial catheter was secured to skin with cyanoacrylate glue and connected to an 84-cm-long extension set that was filled with heparinized saline (0.9% NaCl) solution; the extension set was attached to the horse's halter.

Intra-abdominal cannulation was performed as a modified abdominocentesis at 3 locations in the abdomen (right flank, left flank, and ventrum). The flank sites for cannulation were midway between the center of the tuber ischii and the cranial eminence of the greater tubercle of the humerus at a point 12 cm caudal to the last rib.[14] The ventral abdominal cannula site was identified by visual inspection of the standing horse, and the shortest ground-to-abdomen distance was determined with a tape measure (typically on the linea alba at a point 10 to 15 cm caudal to the xiphoid process). A 5 X 5-cm area at each cannulation site was clipped and aseptically prepared by use of chlorhexidine gluconate and isopropyl alcohol. Mepivacaine (8 mL) was locally infiltrated, and a No.15 scalpel blade was used to make a stab incision into the skin and subcutis.

Measurement of IAP—Direct measurement of IAP was obtained via a 3-way stopcock attached to a sterile 10-gauge 10-cm metal teat cannula filled with heparinized saline solution. Sterile water-based lubricant was applied at the site of cannula insertion to prevent entry of air and development of pneumoperitoneum. The cannula was inserted through the body wall and peritoneum into the intra-abdominal space and held in position by an assistant as reported elsewhere.[14,16] Placement through the peritoneum was confirmed by obtaining peritoneal fluid or by a lack of resistance to flushing with sterile saline solution (< 2 mL). The cannula was connected to an 84-cm-long extension set filled with heparinized saline solution. The other end of the extension set was attached to a pressure transducer[e] and electronic manometer[f] for data collection as reported elsewhere.[16,24] The transducer was checked against other transducers prior to experimentation and the manometer was calibrated annually. For IAP measurement, the transducer was set to zero at the level of cannula insertion into the abdomen, and the 3-way stopcock then was turned to the open position at the cannula end.[14–16,24] Each pressure was recorded in triplicate at the end of expiration as is standard in human medicine.[1]

Arterial blood pressures were obtained by connecting the arterial catheter to a pressure transducer. The transducer for blood pressure was set to zero at the level of the point of the shoulder (estimated level of the right atrium) for standing horses and horses in dorsal recumbency, and at the level of the sternum for horses in right or left lateral recumbency. Direct measurements of arterial pressure were recorded simultaneously with IAP measurements. The transducer for arterial pressures was reset to zero after anesthetized horses were repositioned. All pressure recording systems involved polypropylene tubing 10 filled with heparinized saline solution, which was visually assessed for the presence of air bubbles prior to connection to a horse. When air bubbles were detected, the tubing was with heparinized saline solution until bubbles were no longer evident. All pressure recording systems were assessed for dampening with the square-wave flush test and visual inspection of the pressure waveform for underdampening or overdampening, whereby no appreciable effect of dampening was observed.[25]

Hemodynamic and intra-abdominal variables assessed during the experiments included heart rate determined by ECG, respiratory rate, SAP, MAP, DAP, and IAP at each of the 3 abdominal locations (left flank, right flank and ventral). The APP was calculated for each site of IAP measurement by use of the following equation: $APP_x = MAP_x - IAP_{x,}$ where x is the abdominal location (ie, left flank, right flank, or ventral).

Experimental procedures—After instrumentation was completed, horses were allowed to stand in the stocks uninterrupted for 10 minutes. Baseline hemodynamic and intra-abdominal pressures then were obtained. The intraperitoneal cannulas were removed. Horses were moved to an induction stall and medicated with xylazine hydrochloride[g] (1.1 mg/kg, IV). The intraperitoneal cannulas were replaced. Five minutes after xylazine administration, horses were assessed to determine adequate sedation (lowered head and minimal response to external stimuli) and all variables were measured. Intraperitoneal cannulas were again removed. Anesthesia was induced by IV administration of ketamine hydrochloride[h] (2.2 mg/kg) and diazepam[i] (0.075 mg/kg). Anesthesia was maintained with a continuous infusion of ketamine (2 mg/mL of solution) and guaifenesin guacolate in 5% dextrose solution (50 mg of guaifenesin/mL of solution). Rate of the ketamine-guaifenesin infusion was adjusted to maintain a light plane of anesthesia (minimal to no nystagmus and no spontaneous movements of the limbs, head, or neck) to facilitate animal positioning. Horses were intubated with a 26-mm cuffed orotracheal tube and allowed to spontaneously breathe room air (fraction of inspired oxygen, 0.21).

The order of recumbency positions for each horse was determined with a randomization procedure (a web-based random number generator[j]). Each horse was placed in each recumbency position twice during an experiment. If the same position was designated consecutively, then the horse was placed in a different recumbency (but without obtaining measurements) before being returned to the designated recumbency. For example, when a specific lateral recumbency position was designated consecutively, then the default different recumbency was the opposite lateral side (ie, if right lateral recumbency were consecutively assigned, the measurements were obtained with the horse in right lateral recumbency, the horse then was placed in left lateral recumbency but no measurements were obtained, and the horse then was repositioned into right lateral recumbency and measurements were obtained). When dorsal recumbency was consecutively designated, then the different recumbency was the opposite lateral recumbency to that which had been most recently used (ie, if a horse had most recently been positioned in right lateral recumbency before consecutive designations of dorsal recumbency, then measurements were obtained with the horse in dorsal recumbency, the horse was positioned in left lateral recumbency but no measurements were obtained, and the horse then was repositioned in dorsal recumbency and measurements were obtained). Horses in dorsal recumbency were manually supported by 4 assistants; one was positioned at each limb. 11

Measurements were obtained, cannulas were removed, horses were repositioned, and cannulas then were reinserted. Horses were manually rolled from one body position to the next. A 2-minute period was allowed after manipulation of a horse into a new body position prior to data collection. Ventral IAP was obtained for all 3 recumbency positions. The IAP at the left flank was obtained when horses were in right lateral and dorsal recumbency, whereas IAP at the right flank was obtained when horses were in left lateral and dorsal recumbency.

After data collection was completed, intraperitoneal cannulas were removed and the skin incisions were stapled. Horses remained anesthetized and were immediately enrolled into another unrelated study. Horses were euthanized after completion of that unrelated study.

Statistical analysis—All hemodynamic and intra-abdominal pressure variables were measured in triplicate for each site of measurement and each recumbency. The mean of the 3 values was used for statistical analysis. Variability of IAP and MAP obtained for the duplicated recumbencies (ie, twice each for dorsal, left lateral, and right lateral recumbency) was calculated by use of the following equation:

Variability = ([Y1 sample mean] – [Y2 sample mean])/([{Y1 sample mean + Y2 sample}/2]) X 100 where Y1 and Y2 are the first and second measurements obtained for a body position (left lateral, right lateral, or dorsal recumbency). An arbitrary clinical cutoff value of ≤ 12% was considered acceptable variability for both IAP and MAP.

Statistical testing was performed with commercial software programs.[k,l] Data were assessed for normality with the Shapiro-Wilk and D'Agostino & Pearson omnibus normality tests and found to have a Gaussian distribution. Data were reported as mean ± SD or 95% CI unless otherwise stipulated. Effect of xylazine on all variables (baseline value versus value after xylazine medication) was assessed with paired *t* tests. Intra-abdominal pressure, MAP, and APP were obtained for 2 cannula locations when horses were in lateral recumbency and 3 locations when horses were in dorsal recumbency, which resulted in an unbalanced incomplete block design. The effect of body position on IAP, MAP, and APP for the ventral cannula site was assessed with a repeated-measures 1-way ANOVA with Holm-Sidak post hoc testing. The effect of body position on IAP, MAP, and APP for the flank cannula sites was assessed with paired *t* tests. Significance was set at values of $P < 0.05$ for all analyses.

Results

Horses—The median age of the 9 horses was 21 years (interquartile range, 13 to 25 years). There were 5 geldings and 4 mares; none of the mares was pregnant. Breeds included were Quarter Horse (n = 5), Thoroughbred (2), Standardbred (1), and Rocky Mountain Horse (1). Median body condition score (scale of 1 to 9) was 5 (range, 3 to 8). Median body weight of the horses was 485 kg (interquartile range, 439 to 528 kg).

All horses completed the study. Mean ± SD duration of anesthesia for data collection was 27 ± 3.4 minutes. Median rate for infusion of the ketamine-guaifenesin solution was 2.06 mL/kg/h (95% CI,**12** 1.89 to 2.28 mL/kg/h). Median rate for administration of ketamine and guaifenesin guacolate was 4.12 mg/kg/h (95% CI,**12** 3.79 to 2.28 mg/kg/h) and 103.09 mg/kg/h (95% CI,**12** 94.70 to 113.90 mg/kg/h), respectively. One horse received an additional 200 mg of ketamine IV during the experiment.

Effect of xylazine on hemodynamic and intra-abdominal pressures in horses—At 5 minutes after injection of xylazine, all horses were clinically sedated (to a level adequate for anesthetic induction). The head was lowered and the horse was minimally responsive to external stimuli. Sedation did not have a significant effect on any measured variable **(Table 1)**.

Effect of body position on abdominal pressures in anesthetized horses—There was ≤ 10% variability in mean IAP values obtained for each cannula site for each duplicate recumbency (eg, between the first and second positioning in left lateral recumbency). There was ≤ 12% variability in the MAP obtained for each duplicate recumbency.

Ventral IAP was significantly ($P < 0.001$) lower when horses were in dorsal recumbency, compared with values obtained when horses were in left or right lateral recumbency. Left flank

IAP and right flank IAP were significantly ($P < 0.001$) higher when horses were in dorsal recumbency, compared with values obtained when horses were in lateral recumbency. Directly measured MAP was significantly ($P < 0.001$) lower when horses were positioned in dorsal recumbency, compared with MAP when horses were positioned in left or right lateral recumbency . Ventral APP did not differ significantly ($P = 0.23$) among the 3 recumbency positions. The APP was significantly lower for the left flank ($P < 0.001$) and right flank ($P = 0.002$) when horses were positioned in dorsal recumbency, compared with values measured when horses were in lateral recumbency **(Table 2)**.

Discussion

Direct techniques for measurement of IAP in horses are repeatable and are currently considered to be the most accurate method of acquisition.[14,15] Values for IAP obtained from the flank and ventral aspect of the abdomen of standing horses in the present study were comparable to those reported by use of the same anatomic landmarks for identification in healthy horses.[14–16]

In the present study, we found that hemodynamic and intra-abdominal pressures were unchanged in healthy standing horses in response to IV administration of xylazine. A reduction in heart rate and respiratory rate as well as a brief period of hypertension (followed by hypotension) has been reported after administration of α_2-receptor agonists,[21,26] which is in contrast to the results obtained for the study reported here in which no change in heart rate, respiratory rate, or blood pressure was observed after horses were sedated. Although the horses in the present study were conditioned to their environment and did not display excitement or anxious behavior prior to xylazine administration, we speculate that the process of instrumentation (without sedation) as well as movement to the induction stall may have acted as a stimulus to the sympathetic nervous system that affected the hemodynamic response to xylazine.

To our knowledge, the effect of IV administration of xylazine on IAP has not been evaluated in horses. Sedative administration is used as one type of medical management for IAH in humans, which results in an increase in abdominal compliance and subsequent reduction in IAP.[17,18] Therefore, results of the present study are in contrast with those reported in the human literature; however, in contrast to critically ill humans whereby patients are in a supine position during IAP measurement, the study population for the present study comprised standing healthy horses without preexisting abdominal distension. We speculate that the effects of xylazine and other sedatives may differ in recumbent horses with abdominal disease and potential IAH; however, additional studies are needed to make that determination. Species differences in abdominal conformation, effect of the amount of material in the gastrointestinal tract, body condition score, and IAP acquisition method may also have accounted for these contrasting findings. Analysis of the limited data for horses suggests that there is an effect of body weight on directly measured IAP,[14] and given the wide range of body condition scores of horses in the present study, future studies designed to specifically investigate the effect of body weight and body condition on IAP are warranted.

The common use of sedatives in equine practice suggests that strategic sedation might offer a practical method for medical management of IAH in a clinical setting, assuming sedation is found to be efficacious for reducing IAP in horses with abdominal disease. Further investigation is required in this area. The use of sedatives in humans reportedly reduces variations in IAP measurements by reducing fluctuations in abdominal wall compliance.[27] We did not observe substantial variation in the horses of the present study; however, we were investigating the effects of xylazine in clinically normal standing horses. Abdominal pain in horses and consequent distension of the abdomen might contribute to wider variations in IAP. Evaluations of horses with IAH to investigate IAP variation would be a logical step to determine optimum conditions for the development of standardized methods for the acquisition of IAP. We did not find a significant decrease in IAP after IV administration of a 1.1 mg/kg dose of xylazine to healthy horses, despite the observed clinical effects of sedation; however, further studies are required before definitive conclusions can be made in this area.

In the present study, IAP measured at 3 locations in the abdomen of horses resulted in differences between the values obtained for each site, in response to changes in body position. IAP was increased at the ventral site when horses were positioned in lateral recumbencies and decreased when horses were positioned in dorsal recumbency. The IAP obtained from the flank positions of cannulation was high when horses were positioned in dorsal recumbency but lower when horses were in lateral recumbencies. In humans, the effect of body position on IAP is clearly established.[1] Studies in humans[6–11] reveal that lateral recumbency and various semirecumbent positions (supine positioning with head-of-bed elevation) result in significant increases in IAP, compared with values obtained for patients strictly in a supine position. Values for IAP in humans reportedly are highest when a patient assumes an upright position.[28] The results from these humans studies were all obtained by use of the human consensus intravesicular acquisition method for IAP.[1] In contrast to results for humans,[29,30] indirect methods of IAP measurement in horses are poorly correlated with direct intraperitoneal cannulation.[14,15] Body position also affects IAP in dogs.[13] In that study,[13] investigators found that direct measurement of IAP with an intraperitoneal catheter filled with saline solution yielded higher values with dogs in upright, lateral, and prone positions, compared with results for dogs in a supine position. To our knowledge, the effect of body position on IAP in horses has not been investigated previously, but the findings for the present study are in concordance with those of other species. Body position is a variable that must be considered when developing a standardized, reliable, and repeatable method for abdominal pressure acquisition.

It has been postulated that the human abdominal cavity behaves as a homogenous hydraulic fluid system in accordance with the dynamics of Pascal's law.[1,9,31] Pascal's law states that the pressure exerted anywhere in a confined noncompressible fluid is transmitted equally in all directions throughout the fluid, such that the pressure ratio (initial difference) remains the same. Such a hypothesis means that IAP should remain constant, regardless of body position; however, several human studies[1,6-11] as well as the present study in horses provide contradictory findings. In a study[13] in dogs, investigators found that 3 factors (gravity, visceral shear deformation, and visceral compression) are involved in the determination of IAP. Forces of gravity and visceral shear are considered negligible for human patients lying in a supine position. In such circumstances, visceral compression will correlate directly with intravesicular pressure and IAP.[7] Therefore, recumbency in a supine position allows the abdomen to behave as a hydraulic system. In other body positions, however, shape-unstable viscera (ie, the bladder) become deformed and change abdominal pressure dynamics away from a simple hydrostatic system.[8]

Exact reasons why changes in body position alter IAP remain incompletely defined, but several interacting forces may explain the heterogeneous behavior of the abdomen when patients are placed in different recumbencies. Manipulating recumbency positions in horses changes the intra-abdominal cannula height relative to the bulk of abdominal mass and will increase or decrease gravitational and shear forces accordingly for each of the fixed cannula sites used for this study protocol. The intraperitoneal cannulas were presumed to be in direct contact with gastrointestinal viscera, and we propose that the main effect of body position on IAP was related to movement of viscera and forces of gravity as recumbency was manipulated.

The effects of body position on cardiopulmonary variables have been reported in horses for various conditions, including prolonged anesthesia,[32,33] inhalation anesthesia,[32–36] and positive-pressure ventilation.[36,37] However, the effect of changing recumbency positions on directly measured IAP and calculated APP have not been reported. The MAP is one of the variables required to calculate APP, and we found in the present study that MAP was lower when horses were in dorsal recumbency, compared with MAP when horses were in lateral recumbency. The same effect on blood pressure has been reported in halothane-anesthetized ponies with comparable manipulation of position.[36] Another study[38] performed in dogs anesthetized by IV administration of anesthetic agents (a proportion of which were spontaneously breathing room air) revealed that blood pressure and systemic vascular resistance were significantly lower when dogs were placed in a supine position, compared with results when dogs were in lateral recumbency. We speculate that the change in MAP identified by this study[38] in dogs is the direct result of changes in body position and may be attributable to the weight of abdominal organs compressing the caudal vena cava. Such compression could lead to a decrease in venous return to the heart, which would be followed by a reduction in cardiac output and a subsequent decrease in arterial blood pressure. Similar physiologic processes have been described for pregnant women in the context of human aortocaval compression syndrome.[39] It is important that these changes in MAP with alterations in body position are considered because MAP is integral for the calculation and interpretation of APP.

Calculated APP is a concept analogous to the widely accepted notion of cerebral perfusion pressure (ie, the difference between MAP and intracranial pressure).[12] However, the boundaries of the skull are nonpliable, whereas the abdominal wall is typically compliant. Therefore, it is possible that APP has a wider range of reference values and more variation in healthy subjects than does cranial perfusion pressure. Given the physiologic processes of pressure and high compliancy of the equine abdomen, we speculate that APP ranges in horses might be more expansive than other species. **13** This point of discussion warrants further investigation and should include comparative evaluation among species, in addition to consideration of anatomic features such as diaphragmatic shape.

In the present study, we found that when the ventral cannula site was used as a point of reference, APP remained unchanged regardless of body position. This is because ventral IAP and MAP increased or decreased by comparable magnitudes in response to manipulation of recumbency position. When the left or right flank cannula sites were used as reference points for abdominal pressures, IAP and MAP increased or decreased in opposite directions in response to a change in body position; therefore, values of calculated perfusion pressure were different for lateral versus dorsal recumbency. It has been proposed that APP can be used as a predictor of fatality and may serve as an optimal endpoint for fluid resuscitation in human critical care medicine; however, its usefulness has not yet been fully determined.[2] It is important to remember that APP is a calculated estimation of visceral perfusion. Because location of IAP acquisition and body position both appear to be variables affecting calculated values in horses, interpretation and clinical importance of APP is currently unknown. A standardized method for IAP acquisition is required, which should then be followed by comparison of the resultant APP value with results for other quantifiable methods of visceral perfusion. Investigating IAP measurements in horses with clinical abdominal disease by use of the same 3 locations that were used in the present study might prove useful for determining the utility of obtaining a pressure from the ventral location during routine abdominocentesis in order to identify horses with IAH. Moreover, use of the ventral location to monitor the response to medical or surgical treatments would aid in the understanding of abdominal pressure dynamics in horses with colic.

The data obtained in the present study are applicable to systemically healthy horses that may be subjected to short-term anesthesia with TIVA. The impact of inhalation anesthesia, positive-pressure ventilation, and longer durations of anesthesia on hemodynamic and abdominal perfusion indices remains to be determined, especially for those patients considered to be at high risk for IAH (ie, surgical colic) positioned in dorsal recumbency. These data may serve as preliminary reference values for future studies conducted to investigate the role of APP in the context of IAH, colic, and other abdominal disturbances of horses.

Limitations of the study included the use of TIVA to enable us to manipulate body position. However, it would not have been possible to obtain these data without anesthetizing the horses. The anesthetic drugs chosen for use were designed to minimize cardiovascular instability. All horses were orotracheally intubated to minimize any increase in airway resistance associated with anesthesia that could lead to increases in IAP as a result of high inspiratory airway pressure. The effects of skeletal muscle relaxants used in the study may have impacted abdominal compliance (and caused decreases in IAP); however, almost all anesthetic protocols include a component to induce muscle relaxation as a typically desired effect.

The anesthesia used in the present study provides only initial information on IAP and APP, and the impact of different anesthetic protocols on abdominal pressure variables requires further investigation. The effect of anesthesia over time on hemodynamic and intra-abdominal pressures may also have introduced bias to the results we obtained; however, patient positioning was randomized such that the order of recumbencies was not predetermined or consistent for every horse. The variation in pressure measurements was good (< 10 %) but not perfect. The 2-minute period between changes in recumbency positions and subsequent measurements may have been insufficient to achieve a steady-state IAP. Further studies with different intervals would be needed to determine whether it was sufficient.

We did not measure variables in horses positioned in sternal recumbency. Arterial blood pressures in horses positioned in sternal recumbency during isoflurane-induced anesthesia are similar to those when horses are positioned in dorsal and lateral recumbency.[34] We intended to determine changes in measured pressures in response to clinically relevant body positions. It is uncommon for a horse to be positioned in sternal recumbency for a procedure. Dorsal-to-lateral recumbency and lateral recumbency alone are extremely common positions and were the focus of the experiments.

Another area for consideration includes the fact that IAP was measured at end expiration, rather than end inspiration, as has been the case for some of the evaluations of IAP in horses.[14] The human literature reports that IAP values can be increased at end inspiration and with positive-pressure ventilation[40] (because of a corresponding increase in thoracic cavity pressure, which results in transfer of pressure to the abdomen); thus, the current consensus for critically ill people is to measure IAP at end expiration to attain the most accurate and repeatable values.[1] To our knowledge, there is no information currently available in the veterinary literature to support the use of measurements obtained during either phase of the respiratory cycle; therefore, we chose a protocol in concordance with the consensus for humans. It is possible that the optimal time within the respiratory cycle for measurement of IAP differs between horses and humans because of species differences in the respiratory pattern; however, further investigation is required in this area. The authors propose that this variable is more important in horses with abdominal distension and in those with an increased rate or depth of breathing than in healthy horses.

The fact that intra-abdominal cannulas were removed and reinserted during the transition between body positions is another point of discussion for the present study. This method was required during movement of horses and manipulation of body position to prevent damage to the abdominal wall or organs and breakage of the cannulas. Walking and changes in body position resulted in substantial discordant movement of the penetrated soft tissue; thus, reinsertion of the cannulas ensured instruments were correctly positioned and that there was direct communication with the peritoneal cavity. The depth of the abdominal wall and overlying skin resulted in closure of the penetrating tract once cannulas were removed. The small areas of hair that were clipped at the cannula insertion sites during patient preparation allowed for easy identification of these locations for cannula reinsertion. Repeatability of IAP measurements was good, which indicated that previous cannulation of the abdomen did not affect values obtained during the second measurement. Thus, the authors believe that the method was appropriate and that cannula manipulation did not result in bias during data acquisition.

For the present study, we did not detect significant changes in IAP, MAP, or APP in response to sedation achieved by administration of xylazine in healthy standing horses. We found that manipulation of body position in horses anesthetized with TIVA significantly changed IAP and APP obtained at various sites throughout the abdomen in addition to lowering MAP for horses positioned in dorsal recumbency. Standardized protocols for the measurement of IAP in horses have not yet been developed and are required before use in a clinical setting. The repeatability of measurements and simplicity of the modified-abdominocentesis technique for the study reported here lends itself to use in further investigations. Such investigations should include the evaluation of abdominal pressures in horses with abdominal disease (eg, colic) to determine the prevalence of IAH and the efficacy of therapeutic interventions.

Footnotes 14

a. Carbocaine, Hospira, Lake Forest, Ill.

b. Angiocath, Becton Dickinson, Franklin Lakes, NJ.

c. Surgipro, Covidien, Mansfield, Mass.

d. Surflo, Terumo Medical, Somerset, NJ.

e. Truwave pressure transducer, model PX36N, Edward Lifesciences, Irvine, Calif.

f. Datascope Passport, Maquet GmbH & Co KG, Rastatt, Germany.

g. Anased, Akorn Inc, Decatur, Ill.

h. Ketaset, Fort Dodge Animal Health, Fort Dodge, Iowa.

i. Diazepam, Hospira, Lake Forest, Ill.

j. RANDOM.ORGTitle of webpage. Available at: www.random.org. Accessed March, 21-31, 2011month, day, year.**15**

k. Prism, version 5.0, GraphPad Software Inc, San Diego, Calif.

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Table 1—Mean (95% CI) values for hemodynamic and abdominal pressure variables before and after administration of a sedative preanesthetic medication in 9 healthy standing horses. **18**

Variable	**Baseline**	**After preanesthetic medication**	***P* value***
IAP (mm Hg)			
Left flank	–3.2 (–5.2 to –3.2)	–5.1 (–7.9 to –2.3)	0.12
Right flank	–5.1 (–7.5 to –2.8)	–5.1 (–7.0 to –3.3)	0.51
Ventral	25 (22 to 27)	25 (22 to 28)	0.54
SAP (mm Hg)	134 (126 to 141)	140 (120 to 160)	0.56
MAP (mm Hg)	103 (92 to 113)	100 (86 to 113)	0.71
DAP (mm Hg)	80 (72 to 88)	81 (63 to 99)	0.92
Heart rate (beats/min)	35 (30 to 40)	36 (33 to 39)	0.56
Respiratory rate (breaths/min)	14 (13 to 16)	14 (13 to 15)	0.53
APP (mm Hg)†			
Left flank	106 (95 to 117)	103 (88 to 118)	0.88
Right flank	108 (97 to 119)	103 (89 to 118)	0.71
Ventral	78 (67 to 89)	73 (59 to 87)	0.65

After instrumentation was completed, horses were allowed to stand in the stocks uninterrupted for 10 minutes; baseline hemodynamic and intra-abdominal pressures then were obtained. Horses were moved to an induction stall and medicated with xylazine hydrochloride (1.1 mg/kg, IV). All variables were measured again 5 minutes after xylazine administration.

*Considered significant at $P < 0.05$. †Calculated as MAP – IAP.

Table 2—Mean ± SD (95% CI) values of directly measured IAP, MAP, and calculated APP for 9 healthy anesthetized horses placed in various positions. **18**

Cannula location	Left lateral recumbency			Right lateral recumbency			Dorsal recumbency		
	IAP	MAP	APP	IAP	MAP	APP	IAP	MAP	APP
Left flank	NA	NA	NA	–5.4 ± 3.3 (–8.0 to –2.9)	95.0 ± 19.3 (80.1 to 110.0)	100.0 ± 21.3 (84.1 to 116.9)	15.3 ± 4.6* (11.8 to 18.8)	69.0 ± 14.2 (58.2 to 79.8)	54.0 ± 17.3* (40.5 to 67.0)
Right flank	–8.1 ± 2.1 (–9.7 to –6.5)	82.5 ± 19.2 (67.8 to 97.3)	91.0 ± 18.8 (76.2 to 105.1)	NA	NA	NA	15.3 ± 5.6* (11.1 to 19.5)	70.4 ± 11.9 (61.3 to 79.6)	55.0 ± 14.6* (43.9 to 66.4)
Ventral	11.3 ± 3.3 (8.8 to 13.9)	83.6 ± 14.9 (72.3 to 95.1)	72.0 ± 15.7 (60.2 to 84.4)	13.0 ± 7.1 (7.5 to 18.5)	93.4 ± 17.0 (80.3 to 106.5)	80.0 ± 20.9 (64.3 to 96.5)	–6.7 ± 2.4* (–8.5 to –4.9)	68.8 ± 11.8* (59.8 to 77.9)	76.0 ± 13.4 (65.2 to 85.2)

*Within a row, value differs significantly ($P < 0.05$) from the corresponding value for other body positions.