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Direct intra-abdominal pressures and abdominal perfusion pressures in unsedated normal horses

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Abstract

Objectives—To determine whether direct intra-abdominal pressures (IAP) and calculated direct abdominal perfusion pressures (APP) are location dependent within the abdomen of standing horses. We hypothesize that IAP will be increased and calculated APP will be decreased at a ventral abdominal location (V) when compared to values obtained from the left (LFI) or right flank (RFI).

Design—Prospective experimental design.

Setting—University-based equine research facility.

Animals—Seven healthy adult horses, 4 geldings and 3 mares.

Interventions—Measurements of direct IAP obtained from the RFI, LFI, and V locations via abdominal cannulation and direct arterial blood pressures obtained via catheterization of the transverse facial artery were obtained in fasted, standing, unsedated horses. APP was calculated for each location by the subtraction of IAP from the mean arterial pressure. Differences between sites of measurement for IAP, APP, and their gradients were calculated and compared by ANOVA and *t*-tests.

Measurements and Main Results—Mean flank IAP measurements were subatmospheric and negative compared to ventral IAP values (LFI = −3 mm Hg, RFI = −5 mm Hg, V = 25 mm Hg; $P < 0.001$ between each flank and the ventral location). Ventrum APP was lower than flank APP (V = 82 mm Hg; LFI = 106 mm Hg; RFI = 108 mm Hg; $P = 0.029$ between each flank and the ventral location). Gradient calculations between sites showed the IAP increased and APP decreased from dorsal to ventral ($P < 0.05$) and from right to left ($P = 0.004$) within the abdomen.

Conclusions—IAP and calculated APP are location dependent. These data provide new information regarding abdominal pressure profiles in standing healthy adult horses.

Keywords

equine; intra-abdominal hypertension; visceral perfusion

Introduction

Measurement of intra-abdominal pressure (IAP) is required for the identification of intra-abdominal hypertension (IAH), a condition encountered in approximately 50% of human intensive care unit patients.¹ IAH is associated with significant morbidity and mortality through organ failure and abdominal compartment syndrome (ACS).^{1,2}

Several conditions and therapies have been associated with ACS in people including gastrointestinal emergencies, increased abdominal content (eg, fat, fluid, gas), trauma, sepsis, high-volume fluid resuscitation and tight-abdominal surgical closure.¹ In horses, disorders referable to the acute abdomen are the most frequent reason for hospital admission;³ however, despite the clinical importance of colic in horses, the impact of IAH/ACS has been poorly investigated in equine medicine.⁴ Strategies to treat IAH/ACS in people include intraluminal content evacuation, percutaneous abdominal gas or fluid drainage, sedative analgesia to improve abdominal wall compliance, optimizing systemic perfusion indices, and surgical decompression.² Organ failure occurs as abdominal perfusion pressure (APP) decreases, defined as the difference between the mean arterial pressure (MAP) and IAP. In people, persistent increases in IAP (>20–25 mm Hg) or decreases in APP (<50 mm Hg) are associated with ACS.² To date, cut-off pressures in horses with abdominal disease are unknown.

In people, indirect IAP measurements correlate closely with direct methods. Intravesicular pressure as an indirect measure and minimally invasive technique for IAP determination is considered the technique of choice over direct intraperitoneal cannulation.⁵ Several studies have reported poor correlation between indirect IAP (intravesicular⁶ and intragastric^{7,8}) and direct IAP measured in standing horses. High intra- and interindividual variability observed with indirect techniques makes direct abdominal cannulation the preferred method of IAP assessment in horses.^{6–8}

Limited information exists regarding IAP values in normal horses⁶ and the effect of cannula location within the abdomen on IAP has not been documented. Moreover, normal values for calculated APP in standing horses have not been reported. Considering differences between equine and human abdominal conformation as well as relative visceral mass, we believe that IAP (and APP) may vary depending on the location these measurements are obtained from within the abdomen. The purpose of this study was to document direct IAP, direct MAP, and calculated direct APP in normal standing horses at 3 locations within the abdomen without the influence of sedative drugs.

Materials and Methods

Seven adult horses (>1 year of age) of various breeds were used for this study. Horses were nonpregnant and considered free of abdominal disease based on having a normal physical examination, normal rectal examination, no history of colic or abdominal surgery (6 months prior), and no detectable abnormalities on transabdominal ultrasonography.

Patient preparation

Twenty-four hours before instrumentation, horses were evaluated for the presence of pre-existing abdominal disease. A previous study showed that large intestinal filling is associated with decreased accuracy of direct IAP measurements in horses⁹ and as such, food was withheld for 24 hours, 4 L of mineral oil was administered via nasogastric intubation to promote gut evacuation, and water was withheld 6 hours prior to data collection. Horses were then housed in temperature controlled (25°C) indoor stalls.

Instrumentation

Intra-abdominal cannulation was performed at 3 locations in the abdomen: right flank (RFI), left flank (LFI), and ventrum (V). The location of flank cannulas was identical to a previously described method for RGI IAP measurement.⁶ The ventral abdominal cannula was placed 10 cm caudal to the xiphisternum through the linea alba.

For each cannula insertion site (RFI, LFI, and V), a 5 cm × 5 cm area was clipped and aseptically prepared using chlorhexidine gluconate and isopropyl alcohol. Eight milliliters of mepivacaine was infiltrated locally at the cannulation site. A stab incision was made into the skin and subcutis using a number 15 scalpel blade. A 3-way stopcock was attached to a saline primed 10 cm metal teat cannula with the closed position toward the cannula end. The cannula was then placed through the body wall and peritoneum into the intra-abdominal space and held in position by an assistant. Sterile water-based lubricant was placed at the site of cannula insertion to avoid entry of air.

Direct arterial blood pressure measurements (systolic arterial pressure [SAP], mean arterial pressure [MAP], and diastolic arterial pressure [DAP]) were obtained via an 18-G 1.0" Teflon catheter^a in the transverse facial artery following intradermal mepivacaine instillation. The catheter was secured to the face using adhesive glue and connected to a heparin 0.9% saline primed 84-cm-long extension set that was attached to the horses' halter.

Experimental procedure

All instrumentation and experimental procedures were performed with horses in standing stocks and without sedation. Prior to data collection, a 10-minute time interval elapsed to minimize the effect of stress responses associated with instrumentation on systemic cardiovascular indices. For IAP determinations, a sterile heparin 0.9% saline primed 84-cm-long extension set was attached to the 3-way stopcock on the cannula and connected to a pressure transducer and electronic manometer^b (Figure 1). The 3-way stopcock was turned to the open position at the cannula end and the transducer was zeroed at the level of cannula insertion into the abdomen (Figure 2). Each pressure was recorded in triplicate at the end of inspiration. The order of IAP determinations between each site for each horse was also randomized.

For blood pressure determinations, an electronic transducer was zeroed at the level of the point of the right shoulder. The SAP, MAP, and DAP were recorded in triplicate at the same time as each IAP measurement. The horses' head was held steady in an upright and neutral position for each blood pressure measurement.

Calculated indices

The APP was determined for each location by the following equation:

$$APP_x = MAP_x - IAP_x$$

where x is the RFI, LFI, or V location.

The right and left dorsal-to-ventral (D-V) IAP and APP gradients were calculated by the following equations:

^aTerumo Surflo, Terumo Medical Corporation, Somerset, NJ.

^bDatascope Passport – Maquet GmbH & Co. KG, Rastatt, Germany.

$$IAP_{RFI \text{ or } LFI} D - V \text{ gradient} = IAP_{RFI \text{ or } LFI} - IAP_V$$

and

$$APP_{RFI \text{ or } LFI} D - V \text{ gradient} = APP_{RFI \text{ or } LFI} - APP_V$$

The left-to-right (L-R) and right-to-left (R-L) IAP and APP gradients were calculated by the following equations:

$$\begin{aligned} IAP_{L-R} \text{ gradient} &= IAP_{LFI} - IAP_{RFI} \text{ and } IAP_{R-L} \text{ gradient} = IAP_{RFI} - IAP_{LFI} \\ APP_{L-R} \text{ gradient} &= APP_{LFI} - APP_{RFI} \\ \text{and } APP_{R-L} \text{ gradient} &= APP_{RFI} - APP_{LFI} \end{aligned}$$

All experimental procedures were approved by the institutional animal care and use committee of the Ohio State University prior to the commencement of the study.

Statistical analysis

Data were assessed for normality using the Shapiro–Wilk test. For each pressure measurement taken in triplicate, the mean value was entered into a spreadsheet.^c All data are presented as mean $\pm$ standard deviation.

Statistical analyses were performed using commercial statistical software.^d Comparisons between IAP and APP determinations obtained at each location were performed using a one-way ANOVA with Bonferroni post hoc testing. Differences between IAP gradients and APP gradients for each location were performed using an unpaired Student's *t*-test. Significance was set at $P < 0.05$.

Results

Seven horses had complete datasets for direct IAP, SAP, MAP, and DAP. The mean age was 15 years (3–25 years) with 4 geldings and 3 mares. Breeds included were Quarterhorses (5) and 1 each of Standardbred and Thoroughbred. All horses tolerated preparation and instrumentation and finished the experimental procedure.

The direct IAP, SAP, MAP, DAP, and calculated APP for each location of measurement are presented in Table 1. There were no differences in SAP, MAP, and DAP obtained at each location ($P = 0.88, 0.94, \text{ and } 0.95$, respectively). There was a significant difference in the measured IAP ($P < 0.001$) between each flank locations and the ventral location, where higher IAP was observed ventrally. Similarly, the APP_V was significantly lower ($P = 0.029$) than APP_{RFI} or APP_{LFI} . There was no statistical difference between IAP and APP values between the RFI and LFI ($P > 0.05$).

IAP and APP gradients between locations of measurement are shown in Table 2. There was no statistical difference between the left and right D-V gradients for IAP ($P = 0.26$) or APP ($P = 0.3$). There was a difference between the L-R abdominal gradient and R-L abdominal

^cExcel, Microsoft Inc, Redmond, WA.

^dPrism version 5, GraphPad Software Inc, San Diego, CA.

gradient ($P = 0.004$) where IAP remained subatmospheric but was more negative on the right and became more positive toward the left.

Discussion

We measured IAP and APP in unsedated standing horses at 3 locations within the abdomen to determine whether IAP and APP are consistent throughout. Based on our findings, these data show that direct IAP and calculated APP are location dependent within the standing horse abdomen.

These findings are in contrast to the reports regarding IAP determinations in the context of IAH and ACS in people.¹⁰ IAP is believed to follow Pascal's law that states that the pressure exerted anywhere in a confined incompressible fluid (ie, the abdomen) is isotropic such that the pressure ratio remains the same.¹¹ Based on this assumption, IAP should be similar throughout the abdomen regardless of the location of measurement. However, changes in abdominal compliance are likely contributory to the lack of uniformity among pressure determinations in normal horses. One might speculate that as compliance decreases (ie, with IAH/ACS), the abdominal contour is more rigid and Pascal's law becomes more relevant such that the increased IAP is distributed more uniformly throughout the abdomen. This would make the site of IAP determination less critical. Future studies in horses where increased IAP may be present (eg, intestinal obstruction, pregnancy) may help confirm or refute this theory.

Differences in IAP/APP within the abdomen may also be related to the effect of visceral weight as well as the vertical distance and gravitational force between the dorsal and ventral abdomen. In standing horses, viscera preferentially occupy the ventral abdomen and are subject to gravity. Not surprisingly, visceral weight may therefore increase IAP in the ventral abdomen of standing horses as was observed in the horses in this study. Such gravitational effects are irrelevant in people, as the standard to practice in obtaining intravesicular IAP measurements requires the patient to be in supine position.⁵

In horses, the lack of difference between the left and right D-V gradients implies that the factors causing the increase in ventral IAP are symmetrically distributed throughout the abdomen (ie, gravity). To test the effect of visceral mass on IAP/APP, further investigation of these variables in fasted versus fed horses as well as horses in different recumbencies is required to see if ventrally oriented locations of IAP determination are consistently increased relative to dorsally oriented locations of IAP measurement.

The dorsal abdomen had subatmospheric IAP in both left and right. This may be advantageous to organ perfusion by promoting flow through the abdominal aorta as well as venous return to the caudal vena cava from the viscera. There was also a small equal but opposite IAP/APP gradient between the left and right abdomen where RFI was more negative than the LFI. The exact reasons are unknown but may relate to abdominal organ asymmetry. The spleen is located in the LFI and may be more likely to exert a pressure on the cannula merely by its weight and parenchymous nature. However, in the RFI, the cecal base should be flaccid and nondistended and should be less likely to exert transmural pressure to the peritoneal space in normal standing horses.

Direct IAP measurements obtained in this study from the RFI compare similarly with the previous studies in healthy standing horses.^{6,7} The normal data distribution and the comparable values to previous studies indicate that direct cannulation is a reliable and reproducible method of IAP measurement in normal horses. We chose to assess the IAP/APP in the ventral abdomen to establish normal values that have not previously been

reported. Ventral abdominocentesis is commonly performed as part of the evaluation of acute abdominal disease in horses, and may offer a practical and easy method to determine IAP in the clinical setting. Further investigation evaluating ventral IAP in horses with abdominal disease (eg, colic, hydrops allantois/amnion) is required to determine the diagnostic value of ventral IAP measurements in clinical decision making as has been suggested by previous investigators.^{4,8}

Horses were not intentionally sedated for this experiment as sedative analgesics, among other techniques, have been shown to decrease IAP in people.² We did not want the effect of sedatives to influence the data as we sought to determine direct IAP and APP values in standing healthy horses to establish a reference range that may be useful for future studies on IAH in horses. Of interest, values for RFI IAP were similar in the horses reported in this study compared to a previous study,⁷ where detomidine hydrochloride had been administered 30 months prior to data collection. It is possible that 30 months is sufficient time for the effects of detomidine on IAP to be minimal, especially in a healthy horse. It is also possible that sedative analgesics may not be effective in IAP reduction in normal horses. The authors speculate that the effect of sedative analgesics on IAP/APP is probably significant in the context of IAH rather than in health; however, the effects of pre- and postsedative administration in clinically normal horses as well as horses with abdominal disease on IAP are needed to determine if sedative analgesics affect abdominal pressure profiles. In people, APP has been proposed as a superior goal-directed endpoint for resuscitation than IAP, MAP, pH, base deficit, lactate, or hourly urine output.¹² Future investigation in standing horses with gastrointestinal conditions as well as normal horses are needed to determine if IAH is clinically relevant (by flank and ventrum IAP/APP measurements) and whether targeted therapies aimed at decreasing IAP or increasing APP such as sedative analgesics, percutaneous decompression, and fluid therapy are efficacious and achievable in horses.

Conclusion

Intra-abdominal pressures and APP values are location dependent within the normal equine abdomen. Ventral IAP was positive and increased when compared to LFI or RFI pressures that were subatmospheric. A small but significant IAP and APP gradient exists between the left and right dorsal abdomen, where right pressures are more negative. These data provide new information regarding abdominal pressure profiles and pressure gradients in standing normal horses.

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Abbreviations

ACS	abdominal compartment syndrome
APP	abdominal perfusion pressure
DAP	diastolic arterial pressure
IAH	intra-abdominal hypertension
IAP	intra-abdominal pressure
LFI	left flank
MAP	mean arterial pressure

SAP	systolic arterial pressure
RFL	right flank

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Figure 1.
Instrument setup for the determination of direct intra-abdominal pressure measurement in horses using a metal cannula and electronic pressure transducer.

Figure 2. Right flank direct intra-abdominal pressure determination in a standing horse. The pressure transducer is being held level with the cannula point of entry into the abdomen.

Table 1Direct intra-abdominal pressure and blood pressure measurements in standing unsedated horses ($n = 7$)

	IAP (mm Hg)	SAP (mm Hg)	MAP (mm Hg)	DAP (mm Hg)	APP* (mm Hg)
Left flank	-3 ± 2.5	144 ± 18	107 ± 12	82 ± 14	106 ± 24
Right flank	-5 ± 3.0	140 ± 16	104 ± 10	81 ± 10	108 ± 16
Ventrum	$25 \pm 3.1^{\dagger}$	146 ± 19	108 ± 13	84 ± 14	$82 \pm 23^{\dagger}$

Values recorded as mean $\pm$ standard deviation

* APP calculated from MAP – IAP.

 $^{\dagger} P < 0.05$ between sites of measurement.

Table 2

Calculated direct intra-abdominal pressure and abdominal perfusion pressure gradients in standing unsedated horses ($n = 7$)

	IAP (mm Hg)	APP* (mm Hg)
Left D-V gradient	$28 \pm 3.3^{\dagger}$	$24 \pm 2.7^{\dagger}$
Right D-V gradient	$30 \pm 3.7^{\ddagger}$	$26 \pm 2.8^{\ddagger}$
L-R gradient	$1.9 \pm 2.4^{\dagger\ddagger\ddagger\ddagger}$	$-2 \pm 1.3^{\dagger\ddagger\ddagger\ddagger}$
R-L gradient	$-1.9 \pm 2.4^{\dagger\ddagger\ddagger\ddagger}$	$2 \pm 1.3^{\dagger\ddagger\ddagger\ddagger}$

Values recorded as mean $\pm$ standard deviation

* APP calculated from MAP – IAP.

$^{\dagger}P < 0.05$ between left D-V gradient and L-R or R-L gradients.

$^{\ddagger}P < 0.05$ between right D-V gradient and L-R or R-L gradients.

$^{\dagger\ddagger\ddagger\ddagger}P < 0.05$ between gradients.