Eurasia Specialized Veterinary Publication

International Journal of Veterinary Research and Allied Science

ISSN:3062-357X

2024, Volume 4, Issue 1, Page No: 119-128

Available online at: www.esvpub.com/

Microvascular Perfusion in the Equine Gastrointestinal Tract During Induced Hypotension and Dobutamine Rescue: A Sidestream Dark-Field Microscopy Study

Mikko Vartiainen[1]*, Emilia Miettinen[1]

[1]University of Helsinki, Faculty of Veterinary Medicine, Helsinki, Finland.

***E-mail** ✉ mikko.vartiainen1@gmail.com

ABSTRACT

Horses undergoing abdominal exploratory procedures are susceptible to both hypotension and inadequate tissue perfusion. Mean arterial pressure (MAP) is often considered an indicator of sufficient tissue blood flow, although systemic measures may not accurately mirror microcirculatory dynamics. This investigation assessed MAP, cardiac index, lactate concentration, and four microcirculatory indices in six healthy, anesthetized adult horses undergoing planned laparotomies. Microcirculatory data were collected at three gastrointestinal sites (oral mucosa, colonic serosa, and rectal mucosa) using dark-field microscopy. All macro- and microcirculatory values were recorded during normotension, induced hypotension, and after normotension was re-established through dobutamine administration. Hypotension was generated by increasing the inhaled isoflurane concentration. The induced hypotensive state did not produce consistent or predictable variations in systemic or microvascular perfusion across any of the three intestinal locations examined. Normal blood pressure was successfully restored with dobutamine, but systemic and microvascular perfusion indices remained largely unchanged. These observations indicate that relying solely on mean arterial pressure as a measure of adequate perfusion may not always be reliable.

Keywords: Horse, Colic, Hypotension, Perfusion, Microcirculation, Dobutamine

Received: 02 March 2024
Revised: 28 May 2024
Accepted: 02 June 2024

How to Cite This Article: Vartiainen M, Miettinen E. Microvascular Perfusion in the Equine Gastrointestinal Tract During Induced Hypotension and Dobutamine Rescue: A Sidestream Dark-Field Microscopy Study. Int J Vet Res Allied Sci. 2024;4(1):119-28. https://doi.org/10.51847/RNUxatmndf

Introduction

Horses undergoing abdominal exploratory operations for colic are prone to both systemic and localized tissue hypoperfusion. In gastrointestinal disease cases, compromised microcirculatory blood flow and local ischemia can result in dysfunction or necrosis of intestinal tissue. Cardiovascular alterations in such horses may arise from multiple causes, including anesthesia or endotoxemia [1–3]. These factors can trigger global perfusion deficits throughout the body. Furthermore, in horses suffering from intestinal disorders, perfusion abnormalities can be intensified by local endothelial impairment and inflammatory responses related to the primary illness [4].

Prompt intra-operative detection of perfusion deficits is critical to guide intervention and reduce postoperative complications. However, standard monitoring techniques typically do not assess tissue perfusion directly, particularly not at the microvascular level. Perfusion depends on both blood pressure and vascular resistance. While systemic perfusion equates to cardiac output, this parameter is seldom measured due to the expense and complexity of current methods. Conversely, arterial blood pressure can be easily and precisely obtained, making it a common indicator of cardiovascular performance [5]. Still, hypotension can coexist with normal tissue perfusion, and normotension can occur with inadequate flow, depending on vascular resistance changes.

Moreover, perfusion at specific organ sites may not correspond to global hemodynamic indicators. Hence, monitoring microvascular circulation directly could enhance the detection of regional perfusion deficits.

Sidestream dark field microscopy has emerged as a clinical modality for assessing microvascular perfusion. It has been validated in both human and veterinary applications, including studies on dogs and horses [6–9]. The device emits green light (530 nm) absorbed by erythrocyte hemoglobin, while depolarized reflected light from surrounding tissue returns to the device [10]. This contrast allows visualization of red blood cell flow within capillary networks, producing a high-resolution (326×) real-time image [10]. Such recordings can be qualitatively reviewed or quantitatively analyzed for various microvascular perfusion indices (MPIs): total vessel density (TVD), perfused vessel density (PVD), proportion of perfused vessels (PPV), and microvascular flow index (MFI). In humans and small animals, the sublingual region is most frequently analyzed [8, 9, 11–14], while studies in horses have examined oral mucosa, rectal mucosa, and colonic serosa under both conscious and anesthetized conditions [6, 7]. Concurrent measurements at these three sites in normotensive, anesthetized horses revealed no significant inter-site differences [15].

When hypotension develops, several interventions may be utilized to improve blood pressure and consequently perfusion, such as intravenous fluids, reducing inhalant dosage, or administering cardiovascular stimulants or vasopressors. Dobutamine, a β_1-adrenergic agonist that enhances myocardial contractility, is one of the most frequently used agents for treating intraoperative hypotension in equine anesthesia [16]. Although dobutamine typically restores systemic arterial pressure effectively, tissue hypoperfusion may persist unnoticed. Assessing microvascular function through dark-field microscopy can more accurately depict how systemic hypotension and its correction influence local perfusion. Therefore, the present study aimed to evaluate (1) the impact of systemic hypotension on dark-field microscopy MPIs at three intestinal sites and (2) the effects of restoring normotension with dobutamine on those MPIs. The hypotheses were that, in anesthetized healthy horses, hypotension would reduce MPIs across all regions, and dobutamine treatment would restore MPIs to levels observed during baseline normotension.

Materials and Methods

Animals, anesthesia, and monitoring

This experiment received approval from the University of Georgia Institutional Animal Care and Use Committee (Protocol ID: A2014 05-022-Y3-A0). Six mature, clinically sound horses (mean age 17 years; range 10–29 years), composed of three mares and three geldings, were included. None of the animals showed evidence of cardiovascular or gastrointestinal disorders. The average body mass was 468 kg (ranging from 418 to 575 kg). Prior to inclusion, each horse underwent a full physical assessment confirming normal health status.

A catheter was inserted into the right jugular vein for venous access. Sedation was achieved with xylazine hydrochloride (1.1 mg/kg IV), followed by induction of anesthesia using diazepam (0.05 mg/kg IV) and ketamine hydrochloride (2.2 mg/kg IV). After induction, tracheal intubation was performed, and horses were positioned on their backs. Isoflurane was administered in 100% oxygen, and mechanical ventilation was adjusted to keep end-tidal CO_2 between 35 and 45 mmHg. Polyionic fluids were infused intravenously at an initial rate of 10 mL/kg/h. Direct arterial pressure was continuously monitored through catheterization of the facial artery. Every 5 minutes, heart rate, electrocardiogram, arterial pressure, end-tidal CO_2, oxygen flow, inspired oxygen concentration, tidal volume, exhaled isoflurane, and peak inspiratory pressure were recorded. Arterial blood gas values, electrolyte levels, and cardiac output were measured simultaneously with microcirculatory recordings. Cardiac output was taken twice using lithium dilution via a LiDCO monitor (LiDCO plus, LiDCO Group PLC, London, UK) [17, 18]. The cardiac index was determined by dividing cardiac output by the horse's weight (kg).

Fluid rates and isoflurane concentration were adjusted to maintain normotension (MAP 70–90 mmHg) at the first measurement point. Hypotension (MAP < 60 mmHg) was later induced by raising the isoflurane level for the second measurement. Continuous infusion of dobutamine (0.5 µg/kg/min), adjusted as needed, was used to restore normal pressure (MAP 70–90 mmHg) for the third and final measurement period.

Dark field microscopy image collection

Microvascular imaging was performed using a dark-field microscope (Microscan; MicroVision Medical, Amsterdam, The Netherlands) to capture videos from the oral mucosa, rectal mucosa, and the colonic serosa near the pelvic flexure. The process followed established methods [15, 19]. Recordings were obtained under three

hemodynamic conditions: normotension without support drugs, induced hypotension, and dobutamine-corrected normotension. Blood pressure was stabilized for a minimum of 10 minutes before and during video acquisition for all conditions.

To visualize the large colon, a ventral midline celiotomy was performed under sterile conditions. The abdomen was prepared aseptically and draped before a 20 cm incision was made. The pelvic flexure was gently brought out onto an enterotomy tray for imaging and replaced between sessions. The tray was angled slightly downward from the incision, adjusted to each animal's body conformation to prevent tissue tension, based on the clinical judgment of PK, KE, and JW.

For colonic recordings, the probe tip was placed gently on the serosal surface of the pelvic flexure and held steady using sandbags, allowing the operator to release the device during imaging. Rectal recordings were obtained by inserting the probe about halfway into its disposable sheath (approximately 1–2 cm). Any residual feces were manually removed and rinsed away. The probe was then angled optimally against the rectal mucosa using the table as a reference. For oral imaging, the probe was applied to the gingival mucosa and similarly supported by sandbags. Throughout imaging, warmed sterile saline (0.9% NaCl) was used as necessary to maintain tissue hydration and optimize image quality. Recordings were taken in coordination with mechanical ventilation to minimize motion artifacts.

At least three video clips, each lasting 20 seconds, were captured from each site at every sampling point. The same imaging unit was used for all recordings. Sampling order among sites was randomized, and the probe was repositioned to slightly different but comparable regions between each recording. After completion of the study, additional samples were collected for other approved projects, and the horses were humanely euthanized under general anesthesia.

Measurement of microvascular perfusion parameters

Microvascular assessment followed the recommendations of De Backer *et al*. [19]. From each recording site, three video clips containing a minimum of 50 frames were extracted from the complete recordings. Selection was based on image steadiness, visibility, and overall quality. One investigator (JMW) coded all videos to ensure blinding, after which another researcher (PJK) analyzed the blinded clips using the manufacturer's dedicated program (Automated Vascular Analysis, v3.2; MicroVision Medical, Amsterdam, The Netherlands).

The analysis, described previously in consensus reports [8, 19], yielded the following indices: total vessel density (TVD), proportion of perfused vessels (PPV), perfused vessel density (PVD), and the microvascular flow index (MFI). Details regarding image interpretation and computational procedures for these parameters are documented elsewhere [7, 8, 19].

Statistical evaluation

Normality was examined using histogram inspection, Q–Q plots, and the Shapiro–Wilk test. Homogeneity of variances was assessed by plotting residuals against predicted values and through Levene's test. The effects of blood pressure conditions (normotensive, hypotensive, and dobutamine) on MAP, CI, lactate, and microvascular indices were analyzed using linear marginal models with appropriate covariance structures (compound symmetry, heterogeneous compound symmetry, or unstructured).

To estimate the repeatability of microvascular readings, coefficients of variation (CV) were computed for each horse and tissue site (colon, oral, rectal) across triplicate recordings. The influence of the site, index type, and their interaction on CV values was tested using a linear mixed-effects model, with the horse treated as a random factor and site + variable as fixed effects. Sidak's method was applied for multiple pairwise contrasts when necessary.

Associations between microvascular parameters across different tissues and their relationship with MAP or CI were quantified via correlation coefficients adjusted for repeated measures according to Bland and Altman [20]. Statistical significance was set at $p < 0.05$. All analyses were executed using SPSS v23 (IBM Corp., Armonk, NY, USA).

Results and Discussion

The mean time from anesthesia induction to the beginning of image acquisition was 37 min. Recording all site videos required on average 102 min (range 84–125 min), encompassing translocation of equipment,

exteriorization of the colon, and reinsertion post-recording. Each triplicate set of clips was generally captured within 5 min. Dobutamine infusion lasted 27.17 min (range 20–35 min) at a mean rate of 0.76 µg/kg/min (range 0.27–2 µg/kg/min). Isoflurane concentration was kept as constant as possible but was occasionally adjusted to maintain desired blood pressure and drug infusion levels. Mean IV fluid administration was 3.7 L/h (range 2–10 L/h) with a total mean of 9.5 L per horse (range 7–17 L). Average hematocrit (HCT) equaled 31.2% (range 26–34%), with a mean variation of 3.3% (range 1–6%).

MAP, CI, and lactate data were all normally distributed. MAP differed significantly between the normotensive (81 ± 2 mmHg) and hypotensive (49 ± 2 mmHg) phases ($p < 0.000001$) as well as between the dobutamine (81 ± 1 mmHg) and hypotensive periods ($p < 0.000001$), but not between normotensive and dobutamine states.

For CI, no difference was seen between normotensive (101.39 mL/kg/min) and hypotensive (94.26 mL/kg/min) conditions, whereas dobutamine (115.79 mL/kg/min) produced significantly higher values than both ($p = 0.017$ and $p = 0.0016$, respectively). Mean lactate concentrations were 0.97, 1.08, and 1.25 mmol/L for normotensive, hypotensive, and dobutamine periods, respectively, with only the dobutamine–normotensive contrast reaching significance ($p = 0.017$). All values stayed within the physiological reference (< 2 mmol/L).

Microvascular perfusion indices (MPIs) displayed normal distributions. Average ± SE values appear in **Table 1**. No significant differences in TVD, PVD, or MFI were observed across blood pressure conditions in the colon serosa, oral mucosa, or rectal mucosa **(Figures 1–3)**.

The only significant change was detected for PPV of the oral mucosa between the hypotensive and dobutamine states ($p = 0.045$), while no other contrasts were significant **(Figure 4)**. No meaningful PPV variations occurred for the colon or rectal sites.

There were no cross-tissue correlations among MPIs. Oral TVD and colonic PVD showed moderate positive correlations with CI ($p < 0.05$; $r = 0.503$ and $r = 0.407$, respectively). None of the other indices correlated with CI or MAP at any site. Comprehensive correlation results are summarized in **Table 2**.

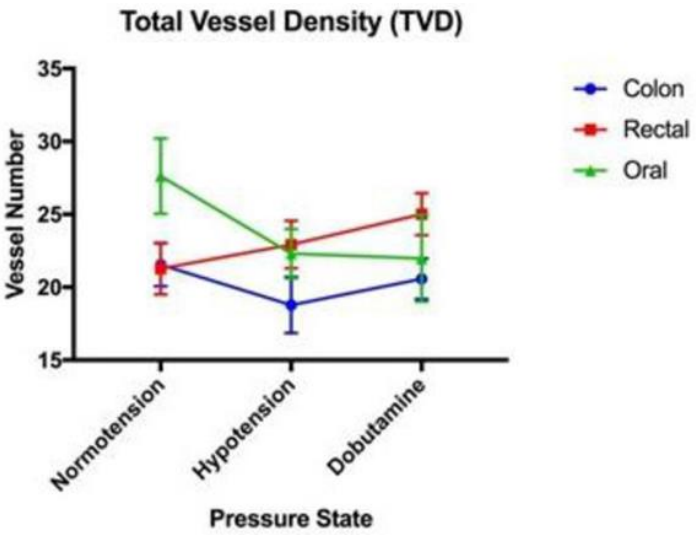

Figure 1. Total Vessel Density (TVD) (mm/mm²):

Illustrates the mean values with standard error bars for total vessel density in oral, rectal, and colonic regions under three hemodynamic states: stable pressure, reduced pressure, and pressure restored by dobutamine infusion.

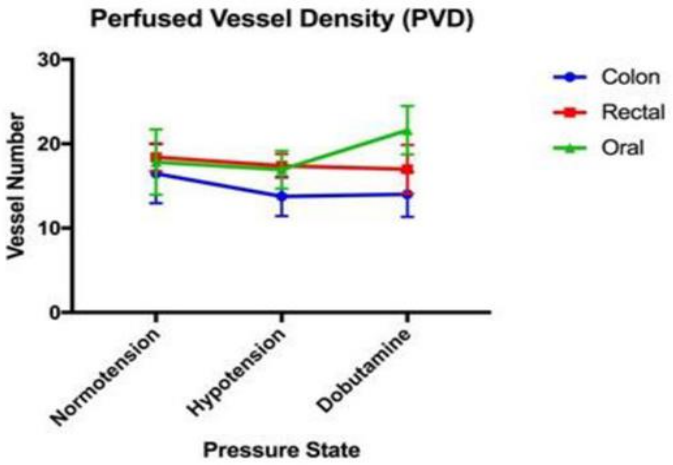

Figure 2. Perfused Vessel Density (PVD) (mm/mm²):

Shows the average and standard error (error bars) for the perfused vessel density within oral, rectal, and colonic tissues during normal, low, and dobutamine-adjusted pressure conditions.

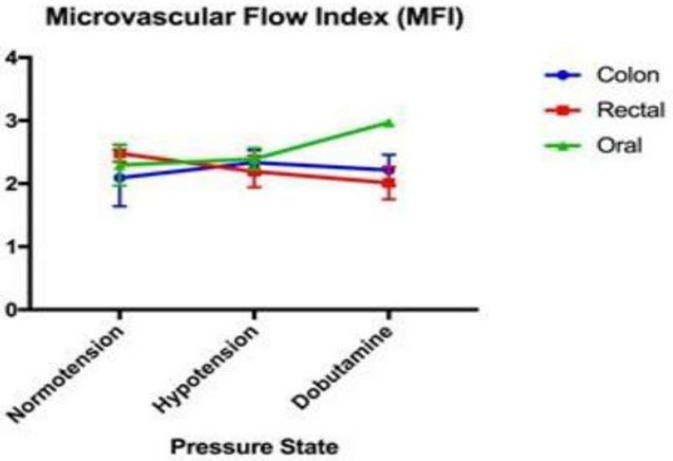

Figure 3. Microvascular Flow Index (MFI):

Displays the mean values with standard error bars for microvascular flow index across oral, rectal, and colonic regions under normotensive, hypotensive, and dobutamine-corrected states.

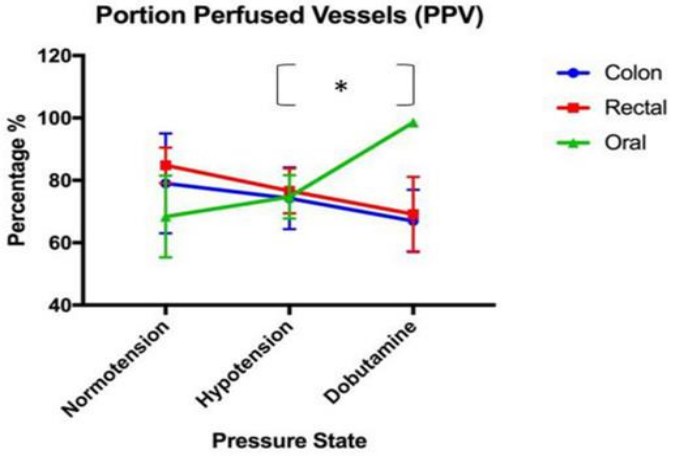

Figure 4. Proportion of Perfused Vessels (PPV) (%):

Compares mean and standard error (error bars) values for the proportion of perfused vessels in the oral, rectal, and colonic mucosa under the three pressure levels (normotension, hypotension, and dobutamine-adjusted

normotension). The asterisk (*) highlights a statistically significant difference in PPV of the oral mucosa between hypotensive and dobutamine conditions.

Table 1. Microvascular Perfusion Data:

Site	Parameter	Normotension	Hypotension	Dobutamine
Oral Mucosa				
	TVD (mm/mm²)	27.63 (±2.59)	22.30 (±1.70)	21.99 (±2.98)
	PVD (mm/mm²)	17.84 (±3.88)	16.93 (±2.24)	21.61 (±2.87)
	PPV (%)	68.38 (±13.10)	74.70 (±6.95)	98.52 (±0.97)
	MFI (units)	2.30 (±0.33)	2.39 (±0.17)	2.97 (±0.07)
Colon Serosa				
	TVD (mm/mm²)	21.55 (±1.48)	18.79 (±1.93)	20.58 (±1.39)
	PVD (mm/mm²)	16.47 (±3.50)	13.76 (±2.32)	14.00 (±2.67)
	PPV (%)	79.03 (±15.98)	74.27 (±9.92)	67.00 (±9.96)
	MFI (units)	2.09 (±0.45)	2.33 (±0.19)	2.21 (±0.25)
Rectal Mucosa				
	TVD (mm/mm²)	21.28 (±1.78)	22.94 (±1.63)	25.02 (±1.45)
	PVD (mm/mm²)	18.42 (±1.65)	17.38 (±1.40)	17.00 (±2.88)
	PPV (%)	84.80 (±5.73)	76.64 (±7.21)	69.17 (±11.97)
	MFI (units)	2.48 (±0.13)	2.19 (±0.25)	2.01 (±0.26)

Lists the mean (± SE) values for TVD, PVD, PPV, and MFI at each location (oral mucosa, rectal mucosa, and colonic serosa) across the three pressure states (normotension, hypotension, and dobutamine-induced normotension).

Table 2. Correlation Summary:

Comparison	Correlation Coefficient (r)	p-value
Colon vs. Oral Mucosa		
TVD	0.177	0.223
PVD	0.209	0.150
PPV	−0.438	0.473
MFI	−0.251	0.082
Colon vs. Rectal Mucosa		
TVD	0.114	0.436
PVD	0.131	0.370
PPV	0.007	0.961
MFI	−0.179	0.220
Colon vs. MAP		
TVD	0.361	0.225
PVD	−0.090	0.770
PPV	−0.133	0.666
MFI	−0.222	0.404
Colon vs. Cardiac Index		
TVD	0.002	0.884
PVD	0.407	0.019
PPV	0.195	0.131
MFI	0.013	0.712
Oral Mucosa vs. MAP		
TVD	0.033	0.553
PVD	0.077	0.358
PPV	0.053	0.449
MFI	0.069	0.386
Oral Mucosa vs. Cardiac Index		
TVD	0.503	0.007

PVD	0.067	0.393
PPV	0.248	0.083
MFI	0.197	0.129
Rectal Mucosa vs. MAP		
TVD	0.004	0.839
PVD	0.036	0.535
PPV	−0.005	0.814
MFI	0.003	0.866
Rectal Mucosa vs. Cardiac Index		
TVD	−0.016	0.68
PVD	−0.001	0.938
PPV	0.000	0.948
MFI	0.013	0.71

Presents the correlation coefficients among microvascular indices (TVD, PVD, PPV, and MFI) for the three sampled regions and their relationships with MAP and CI values.

Findings from this experiment indicate that lowering systemic blood pressure did not reduce microvascular perfusion at any of the gastrointestinal regions assessed. Consequently, the initial hypothesis was rejected, and the secondary assumption—that dobutamine would normalize perfusion to baseline—could not be examined. In anesthetized, clinically normal horses, only weak or absent associations were found between macrovascular readings and microcirculatory parameters across all three gastrointestinal locations during normal, low, and dobutamine-restored pressure states. Likewise, no inter-site relationship was observed between the microvascular variables themselves.

Throughout the study, neither cardiac index nor local microcirculatory flow changed significantly under hypotensive conditions. The unaltered perfusion most likely reflects steady cardiac output and maintained overall blood delivery. Organ perfusion depends on the gradient between arterial and venous pressures, which differs between organs and peripheral regions. Here, two peripheral sites (oral and rectal mucosa) and one visceral organ (colon) were analyzed, showing unchanged capillary flow across the different circulatory states. Still, vasoconstriction in other, unmonitored regions might have occurred to preserve blood delivery to these tissues.

The lack of correlation between sites mirrors prior research [15], although the small sample size must be considered when interpreting results. Anatomical and technical differences could also contribute. Even though the three locations belong to the gastrointestinal tract, they vary in accessibility and structure. The dark field probe required a controlled level of contact pressure, which could have introduced variability. For instance, the oral mucosa lies over bone, leading to more compression compared to the softer rectal or colonic surfaces. Additionally, the rectal wall's folds create inconsistent imaging angles, potentially influencing recordings independent of true perfusion.

Microcirculatory flow is highly variable and rapidly responsive to local metabolic demand. A perfusion change in one region does not necessarily occur in another. Thus, the absence of correlation among the sites may simply represent physiological diversity in regional blood control. The ability of tissues to constrict or dilate independently is essential for maintaining overall hemodynamic balance and allows swift adjustments in systemic resistance—a critical mechanism in circulatory compensation and shock response.

In the present experiment, hypotension was successfully produced by elevating the concentration of inhaled isoflurane [21]. Isoflurane administration influences cardiovascular dynamics primarily through vasodilation and, to a lesser extent, by reducing myocardial contractility [21]. Although vasodilation impacts both arterial and venous circulation, the hypotension observed under isoflurane anesthesia is mainly attributed to arterial relaxation. Determining the total influence of vascular tone on cardiac output is complex; nonetheless, since arterial and venous dilation have opposing effects on stroke volume, the contractility reduction induced by isoflurane remains relatively mild and may have been compensated for by physiological increases in contractile force responding to the elevated stroke volume.

The administration of intravenous fluids to maintain preload likely reduced the detrimental impact of venous dilation on cardiac output. While fluid therapy can produce hemodilution of hemoglobin, hematocrit values stayed within reference intervals for all horses throughout the experiment, with a mean variation of only 3% and a maximum of 6% in a single animal. Therefore, despite the theoretical dilutional influence of intravenous fluids

on hemoglobin concentration and tissue perfusion, this was not considered a confounding element in this study's results.

Isoflurane-induced hypotension was selected as the experimental model because of its reproducibility, simplicity, and clinical importance. Isoflurane is a widely applied inhalation anesthetic in equine practice, where arterial hypotension represents one of its frequent and significant adverse effects. Even though mean arterial pressures consistent with hypotension were reached, systemic lactate, cardiac index, and microvascular perfusion variables remained clinically and—except for lactate—statistically unchanged. These data suggest that healthy equine subjects undergoing routine dorsal recumbency anesthesia can likely preserve sufficient intestinal microcirculation despite systemic hypotension at this level. A major limitation of this work lies in the health condition of the test animals; horses free of disease may exhibit cardiovascular and microcirculatory interactions under isoflurane anesthesia that differ from those of horses with gastrointestinal pathology. Hence, repeating this research in clinically compromised patients, using alternative hypotensive models such as hemorrhage or endotoxemia, is necessary to fully understand these effects.

Dobutamine successfully reversed the hypotensive state in this study. As a positive inotrope, it enhances cardiac output and stroke volume, thereby restoring arterial pressure. In our findings, dobutamine administration increased the cardiac index significantly, yet no notable differences were observed in microvascular perfusion indices or lactate concentration during the treatment phase. This lack of variation may indicate that systemic perfusion remained sufficient or that local autoregulation mechanisms within the microcirculation prevented values from exceeding normal limits.

In a previous investigation, dobutamine administered at 0.5, 1, and 3 mcg/kg/min was evaluated for its influence on systemic hemodynamics and intestinal perfusion (jejunum and colon) in anesthetized, healthy horses. Elevated doses resulted in significant rises in CO, HR, MAP, and regional intestinal blood flow, while 0.5 mcg/kg/min produced no marked increase in jejunal or colonic perfusion [22]. Our observations differ from those at higher doses but align with the lower-dose findings. The average dobutamine infusion rate in this study was 0.76 mcg/kg/min, with titration ranging from 0.27 mcg/kg/min to 2 mcg/kg/min. The consistency between studies likely relates to comparable dosage levels. Additionally, assessment methods for microcirculation differed: we utilized side stream dark field microscopy for colonic blood flow evaluation, whereas the previous research used a micro-lightguide spectrophotometer [22]. These methodological differences could partially explain the variation in outcomes until direct comparisons between the two techniques are available.

It must also be noted that other administered anesthetic agents have known and unavoidable influences on vascular tone [23–25]. To reduce variability, the anesthetic regimen was standardized to limit the effects of injectable agents on microcirculation. Nevertheless, minor adjustments to isoflurane concentration were sometimes necessary to sustain target MAP and/or dobutamine rates, which may have affected individual measurements.

Microcirculatory activity is essential for tissue oxygenation, yet visualizing specific vascular networks remains technically demanding. Systemic parameters (MAP, CO, HR) are simpler to record clinically, so their reliability as indicators of microcirculatory status would be advantageous. Consistent with prior studies, this investigation demonstrated no correlation between macrocirculatory and microcirculatory measurements—particularly in non-diseased subjects [7, 8, 26–31]. The absence of a clear relationship may stem from the use of healthy animals capable of maintaining local autoregulation. Future evaluations of similar vascular territories in diseased horses may yield different outcomes.

Treatments including dobutamine and intravenous fluid administration can influence circulating blood volume and hematocrit levels. When hemoconcentration elevates or hemodilution lowers blood viscosity, tissue perfusion may consequently be affected. Throughout this investigation, hematocrit values remained within the established reference range; therefore, variations in blood viscosity were not considered a contributing factor to the observed results.

This study presents several limitations. The side stream dark field imaging technique can only be applied to serosal or mucosal surfaces, limiting its applicability to other tissues such as skin or deeper organ structures. Motion artifacts generated by colonic peristalsis and mechanical ventilation made high-quality image acquisition challenging. Consequently, although the standard 20-second recording duration was maintained, substantial time was devoted to post-acquisition analysis to identify a minimum of 50 consecutive, high-quality frames suitable for evaluation. Furthermore, the delay between data capture and analysis limits the practicality of this imaging modality for real-time clinical monitoring. Finally, the relatively small sample population may have influenced

statistical outcomes; the number of six experimental subjects was determined by ethical and financial considerations.

Conclusion

In conclusion, within the cohort of healthy, anesthetized adult horses, variations in arterial pressure did not consistently correspond to predicted alterations in either systemic or microvascular perfusion parameters across the three monitored regions. These findings indicate that mean arterial pressure should be interpreted cautiously when used as a surrogate marker for tissue perfusion. Clinically, however, it remains prudent to assume potential reductions in microcirculatory flow whenever systemic hypotension is present. Moreover, administration of dobutamine was validated by its measurable improvements in cardiac index and mean arterial pressure without producing adverse changes in microcirculatory performance. The observed absence of correlation between different microvascular regions suggests that extrapolating the behavior of one vascular bed to represent another could lead to inaccurate clinical assumptions.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

References

1. Bottoms GD, Fessler JF, Roesel OF, Moore AB, Frauenfelder HC. Endotoxin-induced hemodynamic changes in ponies: effects of flunixin meglumine. Am J Vet Res. 1981;42(9):1514–8.
2. Burrows GE. Hemodynamic alterations in the anesthetized pony produced by slow intravenous administration of Escherichia coli endotoxin. Am J Vet Res. 1970;31(11):1975–82.
3. Steffey EP, Howland D Jr. Cardiovascular effects of halothane in the horse. Am J Vet Res. 1978;39(4):611–5.
4. Mitchell K, Schoster A. Chapter 1: Shock: Pathophysiology, Diagnosis, Treatment, Physiologic Response to Trauma. In: Auer J, Stick J, editors. Equine Surgery, 5th ed. St. Louis (MO): Saunders; 2019. p. 1–14.
5. Muir WW, Wade A, Grospitch B. Automatic noninvasive sphygmomanometry in horses. J Am Vet Med Assoc. 1983;182(11):1230–3.
6. Hallowell GD, Lethbridge K, Croxford A. Assessment and reliability of measuring microvascular perfusion in normal adult conscious horses. J Vet Intern Med. 2013;27(3):648–9.
7. Hurcombe SD, Welch BR, Williams JM, Cooper ES, Russell D, Mudge MC. Dark-field microscopy in the assessment of large colon microperfusion and mucosal injury in naturally occurring surgical disease of the equine large colon. Equine Vet J. 2014;46(6):674–80.
8. Peruski AM, Cooper ES. Assessment of microcirculatory changes by use of sidestream dark field microscopy during hemorrhagic shock in dogs. Am J Vet Res. 2011;72(4):438–45.
9. Silverstein DC, Pruett-Saratan II, Drobatz KJ. Measurements of microvascular perfusion in healthy anesthetized dogs using orthogonal polarization spectral imaging. J Vet Emerg Crit Care. 2009;19(6):579–87.
10. Saltzman DJ, Menger MD, Messmer K, Rose R, Kheirabadi BS, Klemcke HG, et al. Systemic and subcutaneous microvascular Po_2 dissociation during 4-h hemorrhagic shock in conscious hamsters. Am J Physiol Heart Circ Physiol. 1996;270(2):H827–36.
11. Boerma EC, Kuiper MA, Kingma WP, Egbers PH, Gerritsen RT, Ince C. Disparity between skin perfusion and sublingual microcirculatory alterations in severe sepsis and septic shock: a prospective observational study. Intensive Care Med. 2008;34(8):1294–300.
12. Boerma EC, van der Voort PHJ, Spronk PE, Ince C. Relationship between sublingual and intestinal microcirculatory perfusion in patients with abdominal sepsis. Crit Care Med. 2007;35(4):1055–60.

13. Goodnight ME, Cooper ES, Butler AL. Assessment of microcirculatory perfusion in healthy anesthetized cats undergoing ovariohysterectomy using sidestream dark field microscopy. J Vet Emerg Crit Care. 2015;25(3):349–57.
14. Petersen SM, Greisen G, Hyttel-Sørensen S, Hahn GH. Sidestream dark field images of the microcirculation: intra-observer reliability and correlation between two semi-quantitative methods for determining flow. BMC Med Imaging. 2014;14(1):14.
15. Kieffer PJ, Williams JM, Shepard MK, Giguère S, Epstein KL. Comparison of the oral and rectal mucosal and colonic serosal microcirculations of healthy, anesthetized horses. Can J Vet Res. 2018;82(1):55–9.
16. Mama KR. Chapter 22: Complications of Inhalation Anesthesia and Their Management. In: Auer J, Stick J, editors. Equine Surgery, 5th ed. St. Louis (MO): Saunders; 2019. p. 340–5.
17. McConachie E, Barton M, Rapoport G, Giguère S. Doppler and volumetric echocardiographic methods for cardiac output measurement in standing adult horses. J Vet Intern Med. 2013;27(2):324–30.
18. Linton RA, Young LE, Marlin DJ, Blissitt KJ, Brearley JC, Jonas MM, et al. Cardiac output measured by lithium dilution, thermodilution, and transesophageal Doppler echocardiography in anesthetized horses. Am J Vet Res. 2000;61(6):731–7.
19. De Backer D, Hollenberg S, Boerma C, Goedhart P, Büchele G, Ospina-Tascón G, et al. How to evaluate the microcirculation: report of a round table conference. Crit Care. 2007;11(5):R101.
20. Bland JM, Altman DG. Statistics notes: calculating correlation coefficients with repeated observations: Part 1 – correlation within subjects. BMJ. 1995;310(6977):446.
21. Steffey EP. Chapter 15: Inhalation Anesthetics and Gases. In: Muir WW, Hubbell JAE, editors. Equine Anesthesia: Monitoring and Emergency Therapy, 2nd ed. St. Louis (MO): Saunders; 2019. p. 288–314.
22. Dancker C, Hopster K, Rohn K, Kästner SB. Effects of dobutamine, dopamine, phenylephrine and noradrenaline on systemic haemodynamics and intestinal perfusion in isoflurane anaesthetised horses. Equine Vet J. 2018;50(1):104–10.
23. Yamashita K, Tsubakishita S, Futaoka S, Ueda I, Hamaguchi H, Seno T, Muir WW. Cardiovascular effects of medetomidine, detomidine and xylazine in horses. J Vet Med Sci. 2000;62(10):1025–32.
24. Wagner AE, Muir WW, Hinchcliff KW. Cardiovascular effects of xylazine and detomidine in horses. Am J Vet Res. 1991;52(5):651–7.
25. Grosenbaugh DA, Muir WW. Cardiorespiratory effects of sevoflurane, isoflurane, and halothane anesthesia in horses. Am J Vet Res. 1998;59(1):101–6.
26. Sakr Y, Dubois MJ, De Backer D, Creteur J, Vincent JL. Persistent microcirculatory alterations are associated with organ failure and death in patients with septic shock. Crit Care Med. 2004;32(9):1825–31.
27. De Backer D, Creteur J, Preiser JC, Dubois MJ, Vincent JL. Microvascular blood flow is altered in patients with sepsis. Am J Respir Crit Care Med. 2002;166(1):98–104.
28. Jhanji S, Lee C, Watson D, Hinds C, Pearse RM. Microvascular flow and tissue oxygenation after major abdominal surgery: association with post-operative complications. Intensive Care Med. 2009;35(4):671–7.
29. Ruiz C, Hernandez G, Godoy C, Downey P, Andresen M, Bruhn A. Sublingual microcirculatory changes during high-volume hemofiltration in hyperdynamic septic shock patients. Crit Care. 2010;14(4):R170.
30. Boswell SA, Scalea TM. Sublingual capnometry: an alternative to gastric tonometry for the management of shock resuscitation. AACN Clin Issues. 2003;14(2):176–84.
31. Olofsson PH, Berg S, Ahn HC, Brudin LH, Vikström T, Johansson KJM. Gastrointestinal microcirculation and cardiopulmonary function during experimentally increased intra-abdominal pressure. Crit Care Med. 2009;37(1):230–9.