

Original Article
Emergency and
Critical Care



Serial venous lactate measurement following gastrointestinal surgery in horses

Lauren E. Smanik ¹, Darla K. Moser ¹, Kris P. Rothers ¹, Eileen S. Hackett ^{1,2,*}

¹Department of Clinical Sciences, Colorado State University, Fort Collins, CO 80523, USA

²Department of Clinical Sciences, Cornell University, Ithaca, NY 14853, USA



Received: Feb 8, 2022

Revised: Jun 13, 2022

Accepted: Jun 17, 2022

Published online: Jul 15, 2022

*Corresponding author:

Eileen S. Hackett

Cornell University, 930 Campus Rd, C2528
Clinical Programs Center Complex, Ithaca, NY
14853, USA.

Email: Eileen.Hackett@cornell.edu

<https://orcid.org/0000-0001-6559-9585>

Results presented in part at the 11th
International Equine Colic Research
Symposium; Dublin, Ireland; July 7-10, 2014.

ABSTRACT

Background: Prospective clinical study of blood lactate concentration in horses undergoing colic surgery is needed to determine utility in outcome prediction.

Objectives: To evaluate venous lactate measurements in horses following colic surgery, including immediately after anesthetic recovery and daily throughout hospitalization, as well as to determine if lactate concentrations were significantly higher in horses that developed postoperative complications or did not survive to hospital discharge.

Methods: Horses > 1 year of age undergoing surgery for colic and recovered from general anesthesia were sampled. A portable lactate meter was used to measure venous samples collected immediately following anesthetic recovery and daily throughout hospitalization. Complications arising during hospitalization and survival to hospital discharge were recorded.

Results: Fifty one horses were enrolled, ranging in age from 2 to 29 years. Lactate concentration immediately following anesthetic recovery was higher in horses that developed complications during hospitalization ($p = 0.046$). The odds of developing complications postoperatively were doubled for horses with a venous lactate concentration > 5 mmol/L. Lactate measurements in non-survivors were significantly higher compared to survivors by 96 h postoperatively ($p < 0.006$).

Conclusions: Higher venous lactate concentrations in the postoperative colic period were associated with an increased risk of complications and death. Results suggest horses with higher venous lactate measurements in recovery are more likely to have postoperative complications, with the odds of developing complications doubled for horses with a venous lactate > 5 mmol/L. Evaluation of venous lactate could provide information on prognosis in the postoperative period for horses with surgical colic.

Keywords: gastrointestinal surgical procedure; gastrointestinal diseases; point-of-care systems; prospective studies

INTRODUCTION

Colic is a major source of life-threatening illness in horses, often resulting in high morbidity and mortality with reported short term survival rates ranging from 54–85% regardless of treatment method [1,2]. When medical therapy does not allow resolution of colic signs,

ORCID iDs

Lauren E. Smanik
<https://orcid.org/0000-0001-7226-5807>
Darla K. Moser
<https://orcid.org/0000-0002-6745-8679>
Kris P. Rothers
<https://orcid.org/0000-0002-3095-8151>
Eileen S. Hackett
<https://orcid.org/0000-0001-6559-9585>

Author Contributions

Conceptualization: Hackett ES; Data curation: Moser DK, Rothers KP; Formal analysis: Smanik LE, Hackett ES; Funding acquisition: Hackett ES; Methodology: Moser DK, Hackett ES; Project administration: Moser DK, Rothers KP; Writing - original draft: Smanik LE, Hackett ES; Writing - review & editing: Moser DK, Rothers KP.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This study was provided by the Colorado State University Center for Companion Animal Studies and the Colorado State University Advances in Equine Health Fund.

surgical intervention may be necessary [3,4]. Both due to the violent nature of colic requiring surgical correction and to improve patient outcome, owners and veterinarians must often make rapid decisions regarding care of the animal. For owners, the decision to pursue veterinary treatment is frequently based on prognosis; however, prognosis is often difficult to predict, especially in the immediate postoperative period, as variable survival rates have been reported based on lesion type, cardiovascular status, and the occurrence of postoperative complications [2].

Lactate is the end product of anaerobic glycolysis, with lactic acidosis occurring in cases of tissue hypoxia secondary to various causes of hypoperfusion [5]. Inadequate intestinal perfusion and ischemia result in increased lactate concentrations in both the peritoneal fluid and blood of horses suffering from colic [6]. Measurement of blood lactate concentration in horses presenting for colic surgery can help guide decision making in the preoperative period, as well as monitoring the response to treatment [6-9]. It has been suggested that horses with persistently abnormal or increasing plasma L-lactate concentrations following colic surgery have a guarded prognosis for survival [7]. Higher preoperative venous and immediate post-anesthetic recovery arterial blood lactate have also been associated with an increased risk of in-hospital complications and death in horses undergoing surgery for colic, suggesting postoperative blood lactate concentrations could be beneficial in predicting prognosis following colic surgery [9,10].

The objectives of this prospective study were (1) to evaluate venous lactate measurements in horses after colic surgery using a stall-side portable lactate analyzer, both immediately following anesthetic recovery and daily throughout hospitalization, and (2) to compare venous lactate concentrations between horses that developed postoperative complications or failed to survive to hospital discharge and those that did not. Based on clinical impression and previous published evidence, we hypothesized that postoperative blood lactate concentrations would be higher in horses that developed postoperative complications and lower in those that survived to hospital discharge.

MATERIALS AND METHODS

Animals

Following informed consent, client-owned horses > 1 year of age that were admitted to the Colorado State University Veterinary Teaching Hospital over a 23-month period, underwent colic surgery, and recovered from general anesthesia were enrolled in this study. The study was approved by the Colorado State University Institutional Animal Care and Use Committee (No. 11-2650A).

Procedures

All case information was noted prospectively on a data recording sheet during hospitalization. A direct venipuncture sample was taken postoperatively from each patient within 60 minutes of standing from general anesthesia, either from the jugular or cephalic veins. This time frame was chosen based on previously published data reporting the stability of blood lactate following anesthetic recovery.¹¹ The time interval between completion of surgery, standing, and the initial sampling time was recorded. In addition to clinical parameters, serial lactate measurements were also recorded from venous samples obtained 24 h after recovery and once daily throughout the remainder of hospitalization. A portable

lactate analyzer (Accutrend, Roche Diagnostics, Indianapolis, IN, USA) was used to measure venous lactate concentration immediately following blood sampling.

Measures of outcome

Postoperative complications occurring prior to hospital discharge, the duration (days) of hospitalization, and short-term survival were documented. In horses that experienced colic pain postoperatively, the severity of pain was graded as mild, moderate or severe, as previously described [2]. Short term survival was defined as survival to hospital discharge. Horses in the nonsurvival group were those that survived surgery but were euthanized or died prior to hospital discharge.

Data analysis

Data were entered into a computer spreadsheet and descriptive statistics were generated. Categorical variables included breed, sex, severity of illness at admission (mild, moderate, severe), survival to hospital discharge (yes or no), lesion localization (large vs. small intestine), lesion type (strangulating vs non-strangulating), whether an intestinal resection was performed, occurrence of postoperative complications (yes or no), and the type of postoperative complication observed: postoperative pulse rate (< 60 bpm vs. \geq 60 bpm), postoperative rectal temperature (< 101.5°F vs. \geq 101.5°F), hyperemic mucous membranes (yes or no), elevated digital pulses (yes or no), occurrence of nasogastric reflux (yes or no), signs of colic pain (yes or no), and severity of colic pain (mild, moderate, severe). Continuous variables included age, duration (days) of hospitalization, time (days) with pulse rate \geq 60 bpm, liters of nasogastric reflex obtained, duration (days) of nasogastric reflux, time (minutes) from standing in anesthetic recovery to first lactate measurement, time (minutes) from completion of surgery to first lactate measurement, and serial lactate measurement (mmol/L) at the pre-determined timepoints.

All continuous variables underwent Shapiro-Wilk analysis for normality. As variables were not normally distributed, continuous data was reported as median and interquartile range (IQR). A Mann-Whitney test was used to evaluate the difference in blood lactate concentration between groups for the outcomes of short-term survival and postoperative complications. A Wilcoxon matched-pair signed rank test was used to evaluate the differences in blood lactate concentrations between sampling times. The odds ratio of developing postoperative complications prior to hospital discharge were calculated based on previously published lactate cut-offs [10]. Mixed effects modelling was utilized to evaluate whether venous lactate concentration differed between horses with and without post-operative complications and between survivors and non-survivors. The level of significance for all comparisons was considered $p < 0.05$.

RESULTS

Fifty-one horses were enrolled in this study: 28 Quarter Horses, 8 Warmbloods, 5 Arabians, 3 Thoroughbreds, 2 American Paint Horses, 2 gaited horses, 1 draft horse, 1 Miniature Horse, and 1 Mustang. Horses ranged in age from 2 to 29 years old, with a median (IQR) age of 11 (8–15) years. There were 26 mares, 24 geldings, and 1 stallion. The median (IQR) duration of hospitalization for this sample population was 5 (4–7) days. Gastrointestinal lesions were localized to the large intestines ($n = 46$) and small intestines ($n = 5$), with 23 strangulating lesions and 28 non-strangulating. Seven horses underwent intestinal resection as part of their surgical treatment. Forty-two (82%) horses survived to hospital discharge. Of the 9 horses that did not survive, 8 horses were humanely euthanized and 1 died from cardiac arrest 6 days postoperatively. No

significant difference was found for the median age or duration of hospitalization between non-survivors (12 years; 5 days) and survivors (9 years; 5 days), respectively ($p > 0.05$).

Thirty horses (59%) developed postoperative complications during hospitalization, including all 9 non-survivors. Of the 42 horses that survived to hospital discharge, 21 (50%) developed postoperative complications (Table 1). Twelve horses exhibited signs of colic pain after their initial colic surgery, with 4 each graded as mild, moderate, and severe. No horses with mild or moderate colic pain postoperatively underwent repeat celiotomy. Three of the four horses with severe colic pain were euthanized and the surviving horse underwent repeat celiotomy. No significant difference ($p > 0.05$) was found for age between horses that developed postoperative complications (median [IQR] = 11.5 [8.25–15] years) and those that did not (median [IQR] = 11 [8–15] years). The duration of hospitalization was longer ($p = 0.009$) for horses that developed postoperative complications (median [IQR] = 6 [4.25–8] days) compared to those that did not develop complications (median [IQR] = 4 [4–5] days). Venous lactate concentration was higher in horses that developed postoperative complications ($p < 0.001$) (Fig. 1).

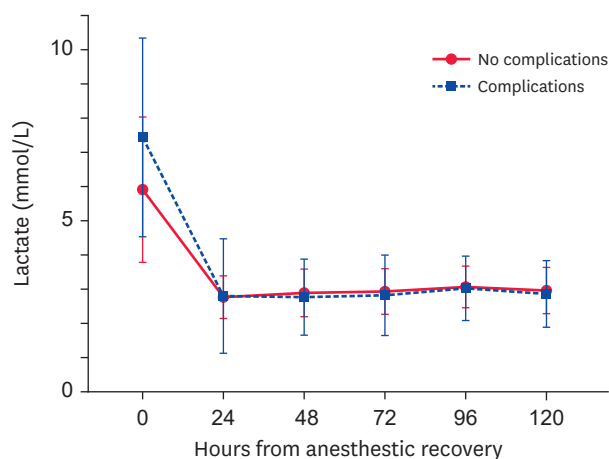


Fig. 1. Venous lactate concentration (mmol/L) in horses over five days following anesthetic recovery from colic surgery in horses that had no post-operative complications and horses that developed post-operative complications.

Table 1. Summary of the complications observed following colic surgery in 50 horses, including the overall number of occurrences and the distribution between survivors and non-survivors

Variables	Overall	Survivors	Non-survivors
Pulse rate \geq 60 bpm	20	11	9
Duration (days)	1 [1–2]	1 [1–2]	1 [1–3]
Hyperemic mucous membranes	12	4	8
Elevated digital pulses	4	2	2
Rectal temperature \geq 101.5F	14	6	8
Duration (days)	1 [1–2]	1 [1–1.75]	1 [1–1.25]
Nasogastric reflux	13	8	5
Duration (days)	2 [1–2]	2 [1–2]	2 [1–2]
Total liters obtained	23 [11–66]	20.5 [14.25–43]	66 [18–66]
Signs of colic pain	12	6	6
Mild	4	4	0
Moderate	4	1	3
Severe	4	1	3
Incisional complications (drainage, infection, or partial dehiscence)	5	4	1
Other complications ^a	6	1	5

Information on complication duration, as well as total liters obtained in the case of nasogastric reflux, is presented for select complications as median [interquartile range].

^aCardiac arrest (n = 1), coagulopathy (n = 2), hemorrhagic diarrhea (n = 2), gastric rupture (n = 1).

Table 2. Summary of serial venous lactate results in 50 horses following anesthetic recovery from colic surgery

Sample time	Number sampled	Overall	Survivors	Non-survivors	<i>p</i> value	Complications	No complications	<i>p</i> value
0 h	51	6.5 ^a [4.9–8.2]	6.6 [4.9–7.9]	6.3 [5.1–9.0]	0.384	6.8 [5.4–9.8]	6.5 [4.6–7.2]	0.046 ^c
24 h	51	2.7 ^b [2.2–3.0]	2.7 [2.2–3.0]	2.6 [2.2–3.5]	0.757	2.6 [2.1–3.0]	2.8 [2.6–3.2]	0.192
48 h	48	2.8 ^b [2.3–3.3]	2.7 [2.3–3.3]	2.8 [1.9–4.7]	0.179	2.6 [1.9–3.3]	2.8 [2.4–3.4]	0.677
72 h	45	3.0 ^b [2.1–3.4]	3 [2–4]	3 [2–4]	0.088	2.9 [1.9–3.7]	3.0 [2.7–3.3]	0.711
96 h	40	3.2 ^b [2.5–3.3]	3.1 [2.5–3.3]	3.6 [3.1–4.9]	0.006 ^c	3.2 [2.4–3.3]	3.2 [2.6–3.4]	0.884
120 h	24	2.7 ^b [2.3–3.1]	2.6 [2.3–3.0]	3.9 [2.6–4.8]	0.062	2.6 [2.3–3.2]	3.0 [2.4–3.3]	0.663

Lactate results (mmol/L) are reported as median [interquartile range].

^{a,b}Significant differences in overall lactate measurement by sampling time; ^cSignificant differences in lactate measurement by outcome; *p* < 0.05.

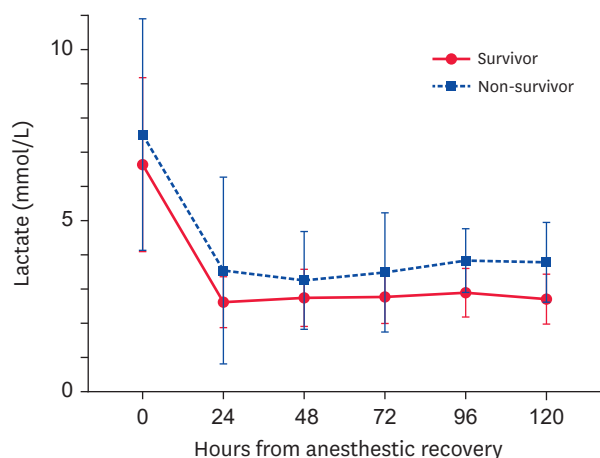


Fig. 2. Venous lactate concentration (mmol/L) in horses over five days following anesthetic recovery from colic surgery in horses that survived to hospital discharge and non-survivors.

The first blood sample for lactate measurement was obtained a median (IQR) of 4 (2–9) minutes after standing from anesthetic recovery and a median (IQR) of 78 (65–88) minutes after completion of surgery. Lactate measurement immediately following anesthetic recovery (median [IQR] = 6.5 [4.9–8.2] mmol/L) was higher than any other time point evaluated (**Table 2**; *p* < 0.001), and in horses that developed complications during hospitalization (median [IQR] = 6.8 [5.4–9.8] mmol/L; *p* = 0.046) compared to those that did not develop complications (median [IQR] = 6.5 [4.6–7.2] mmol/L). The odds of developing postoperative complications were doubled for horses with a venous lactate concentration > 5 mmol/L. Lactate concentrations were increased 96 h after colic surgery (**Table 2**; *p* = 0.006) in non-survivors (median [IQR] = 3.6 [3.1–4.9] mmol/L) compared to survivors (median [IQR] = 3.1 [2.5–3.3] mmol/L), with no difference between these two groups by 120 h postoperatively (*p* = 0.062). In the horse that underwent repeat celiotomy, lactate measurements included in this study were only those taken prior to the second surgery (0 and 24 h). Overall, venous lactate concentration was higher in non-surviving horses than survivors (*p* < 0.001) (**Fig. 2**).

DISCUSSION

This study was the first to follow venous lactate concentrations in horses following colic surgery and evaluate the association between lactate concentration and postoperative outcome. The results from this study suggest horses with higher venous lactate measurements in recovery are more likely to have postoperative complications, with the odds of developing complications doubled for horses with venous lactate > 5 mmol/L. The increases in venous lactate in horses developing complications were most notable

immediately following anesthetic recovery. Increased venous blood lactate concentration throughout hospitalization after gastrointestinal surgery might also indicate an increased likelihood of nonsurvival, as lactate measurements in non-survivors were significantly higher compared to survivors by 96 h postoperatively. Our hypothesis that postoperative blood lactate concentrations would be higher in horses that developed postoperative complications and lower in those that survived to hospital discharge was only partially supported as these statements were not true for every timepoint, although non-survivors were higher postoperatively as supported by mixed effects modeling and this increase was consistent graphically. Evaluation of venous lactate can provide information on prognosis in the postoperative period for horses with surgical colic; however, the utility of serial lactate measurement still warrants further investigation.

A similar study has been performed in which the authors evaluated plasma L-lactate concentrations in 34 horses undergoing emergency colic surgery at admission and at 12, 24, 48, and 72 h postoperatively [7]. The median L-lactate concentration was significantly higher in non-survivors at 24 and 72 h postoperatively compared to survivors; however, there was no significant association between increased L-lactate at hospital admission and the likelihood of survival. This study suggested that persistently increased L-lactate could be a poor prognostic indicator, possible causes of which included continued systemic cardiovascular dysfunction and intestinal compromise [7]. Despite previous reports in which preoperative venous lactate concentration was predictive for outcome in colic horses [9,12], not all horses with elevated preoperative lactate concentrations will have complicated recovery periods [10]. In the present study, a significant increase in blood lactate for non-survivors relative to survivors was not seen until 96 h postoperatively. Postoperative lactate accumulation in non-survivors has been suggested, indicating that change in lactate over time may be a more useful prognostic indicator in critically-ill horses [8]. Our study also highlights that failure of venous lactate to return to normal concentrations is likely a poor prognostic indicator in the days following colic surgery.

Increases in arterial lactate in recovery have been associated with a greater relative risk of postoperative complications and death in horses following gastrointestinal surgery [10]. Though arterial lactate was not measured in the present study, the odds of developing postoperative complications were doubled for horses with a venous lactate > 5 mmol/L. In contrast, the present study showed no significant difference in venous blood lactate immediately following anesthetic recovery between survivors and non-survivors. This may have been due to the relatively low number of non-surviving horses in this study. Despite there being a statistically significant difference in venous blood lactate immediately following anesthetic recovery between horses that developed postoperative complications and those that did not, there was not a clear increase in lactate concentrations in the former. Additionally, there has been shown to be a spike in plasma lactate concentration immediately following anesthetic recovery in both healthy horses and those undergoing colic surgery [10,11]. A previous study showed an increase in muscle lactate in both equine populations (healthy vs. colic) throughout anesthesia, secondary to increased anaerobic metabolism within the musculature, without a concurrent increase in plasma lactate until after recovery from anesthesia [11]. This was suggested to be secondary to improved tissue perfusion and venous drainage after standing, resulting in the reported ischemic reperfusion phenomenon [13], as well as small increases in plasma lactate from the work of standing [11]. Recovery lactate concentrations may also be influenced by the length of recovery and the degree of hemoconcentration (and subsequent hypoperfusion) during this time period [10]. Finally, when compared to normal horses,

postoperative lactate concentrations have been reported to remain elevated for up to 8 h after surgery [11]. This further supports the idea that measuring lactate concentration at a single timepoint does not appear to be a useful prognostic tool alone.

Due to the difficulty of obtaining serial arterial blood samples in non-anesthetized horses, venous blood samples were analyzed in the present study. In addition, a stall-side portable lactate analyzer was used instead of a blood gas analyzer, decreasing both time and cost of analysis. The specific point-of-care device used to measure lactate concentration in the present study has been previously validated in horses [14]. Investigators compared whole blood samples measured on the point-of-care device with a commercial blood gas analyzer and found moderate agreement in lactate concentrations with concordance analysis. Further, results suggested that plasma measurement might be less variable and more accurate than whole blood measurement [14]. Whole blood samples were evaluated in the present study and it is unknown the degree to which variability in serial measurement of lactate concentration was due to the analysis method selected.

Results of the present study suggest horses with higher venous lactate measurements in recovery are more likely to have postoperative complications, with the odds of developing complications doubled for horses with a venous lactate >5mmol/L. The association between postoperative venous lactate concentrations and onset of complications in horses undergoing gastrointestinal surgery warrants further investigation as it could provide additional information on prognosis in the postoperative period for horses with surgical colic.

REFERENCES

1. van der Linden MA, Laffont CM, Sloet van Oldruitenborgh-Oosterbaan MM. Prognosis in equine medical and surgical colic. *J Vet Intern Med.* 2003;17(3):343-348.
[PUBMED](#) | [CROSSREF](#)
2. Mair TS, Smith LJ. Survival and complication rates in 300 horses undergoing surgical treatment of colic. Part 1: short-term survival following a single laparotomy. *Equine Vet J.* 2005;37(4):296-302.
[PUBMED](#) | [CROSSREF](#)
3. Hillyer MH, Taylor FG, French NP. A cross-sectional study of colic in horses on thoroughbred training premises in the British Isles in 1997. *Equine Vet J.* 2001;33(4):380-385.
[PUBMED](#) | [CROSSREF](#)
4. Marshall J, Blikslager A. Colic: diagnosis, surgical decision, preoperative management, and surgical approaches to the abdomen. In: Auer J, Stick J, Kummerle J, Prange T, editors. *Equine Surgery.* 5th ed. Saint Louis: Elsevier, Inc.; 2019, 521-528.
5. De Backer D. Lactic acidosis. *Intensive Care Med.* 2003;29(5):699-702.
[PUBMED](#) | [CROSSREF](#)
6. Delesalle C, Dewulf J, Lefebvre RA, Schuurkes JA, Proot J, Lefere L, et al. Determination of lactate concentrations in blood plasma and peritoneal fluid in horses with colic by an Accusport analyzer. *J Vet Intern Med.* 2007;21(2):293-301.
[PUBMED](#) | [CROSSREF](#)
7. Radcliffe RM, Divers TJ, Fletcher DJ, Mohammed H, Kraus MS. Evaluation of L-lactate and cardiac troponin I in horses undergoing emergency abdominal surgery. *J Vet Emerg Crit Care (San Antonio).* 2012;22(3):313-319.
[PUBMED](#) | [CROSSREF](#)
8. Tennent-Brown BS, Wilkins PA, Lindborg S, Russell G, Boston RC. Sequential plasma lactate concentrations as prognostic indicators in adult equine emergencies. *J Vet Intern Med.* 2010;24(1):198-205.
[PUBMED](#) | [CROSSREF](#)
9. Johnston K, Holcombe SJ, Hauptman JG. Plasma lactate as a predictor of colonic viability and survival after 360 degrees volvulus of the ascending colon in horses. *Vet Surg.* 2007;36(6):563-567.
[PUBMED](#) | [CROSSREF](#)

10. McCoy AM, Hackett ES, Wagner AE, Mama KR, Hendrickson DA. Pulmonary gas exchange and plasma lactate in horses with gastrointestinal disease undergoing emergency exploratory laparotomy: a comparison with an elective surgery horse population. *Vet Surg.* 2011;40(5):601-609.
[PUBMED](#) | [CROSSREF](#)
11. Edner AH, Nyman GC, Essén-Gustavsson B. Metabolism before, during and after anaesthesia in colic and healthy horses. *Acta Vet Scand.* 2007;49(1):34.
[PUBMED](#) | [CROSSREF](#)
12. Orr KE, Baker WT, Lynch TM, Hughes FE, Clark CK, Slone DE Jr, et al. Prognostic value of colonic and peripheral venous lactate measurements in horses with large colon volvulus. *Vet Surg.* 2020;49(3):472-479.
[PUBMED](#) | [CROSSREF](#)
13. Serteyn D, Pincemail G, Deby C, Philippart C, Lamy M. Equine postanesthetic myositis: an ischemic reperfusion phenomenon. *J Vet Anaesth.* 1991;18 Suppl:319-322.
[CROSSREF](#)
14. Tennent-Brown BS, Wilkins PA, Lindborg S, Russell G, Boston RC. Assessment of a point-of-care lactate monitor in emergency admissions of adult horses to a referral hospital. *J Vet Intern Med.* 2007;21(5):1090-1098.
[PUBMED](#) | [CROSSREF](#)