How to use Lactate in Equine Practice

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The measurement of blood lactate concentration has gained popularity in veterinary patients in recent years, following its acceptance in human critical care as an important therapeutic and prognostic indicator for a range of clinical syndromes. Traditionally, increases in blood lactate concentration have been associated with hypoperfusion and tissue hypoxia; however, hyperlactatemia may also occur under conditions in which tissue oxygenation is maintained. The advent of hand-held portable lactate analyzers can provide rapid diagnostic and prognostic information in the critically ill equine patient, even in the field. The purpose of this article is to provide equine practitioners with a review of current literature regarding the physiology and pathophysiology of lactate production, applications of lactate monitoring in human and small animal critical care, and current and potential indications for lactate measurement in the horse. The usefulness of lactate as a predictor of survival, trigger point for therapeutic intervention, and indicator of disease severity and response to treatment in a range of commonly encountered clinical syndromes is discussed.

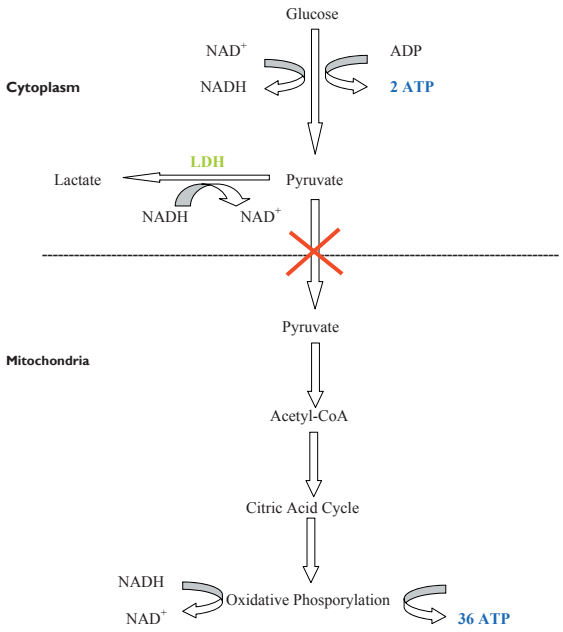
What is lactate?

Lactate is the ionized form of lactic acid, and exists as two stereoisomers: L-lactate and D-lactate. L-lactate is produced by cellular metabolism in mammalian cells, while D-lactate is produced by bacterial glucose metabolism. As such, L-lactate is the isomer which increases in hyperlactatemia and lactic acidosis in equine patients and is also the form measured by commercial lactate analyzers. Conversely, lactic acidosis due to increases in D-lactate is uncommon, although has been described in people with short bowel syndrome, ruminants with grain overload and calves with diarrhoea.[1]

Lactate production and metabolism: Back to bio-chemistry!

During glycolysis, the first step in the metabolism of glucose, glucose is converted to pyruvate in the cytoplasm of cells. No oxygen is required for this initial process, which results in the production of energy in the form of adenosine triphosphate (ATP); however only 2 molecules of ATP are produced per molecule of glucose. The enzyme cofactor nicotinamide adenine dinucleotide (NAD+) is required for the production of ATP from adenosine diphosphate (ADP). During the conversion of glucose to pyruvate, NAD+ is reduced to NADH. Under aerobic conditions, pyruvate then enters the mitochondria of the cell, and is converted to acetyl coenzyme A which enters the citric acid cycle (Kreb's cycle). Oxidative phosphorylation follows, NADH is oxidized back to NAD+ to enable ATP production to continue, and ultimately an additional 36 molecules of ATP are produced. Under anaerobic conditions, including hypoperfusion, pyruvate can no longer enter the mitochondria, thereby limiting energy production to glycolysis in the cytoplasm (Figure 1).

Figure 1: Energy Production in aerobic and anerobic glycolosis is in the form of adenosine triphosphate (ATP). During anaerobic glycolysis (X), pyruvate can no longer diffuse into the mitochondria to be converted to acetyl-CoA and enter the citric acid cycle. Pyruvate is converted to lactate by the enzyme lactate dehydrogenase (LDH). Lactate production occurs during both aerobic and anaerobic glycolosis.

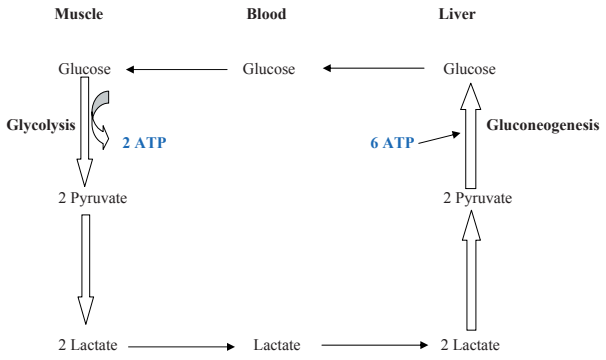


Lactate is constantly being produced in low concentrations under normal conditions of aerobic metabolism, with some of the pyruvate produced in the cytoplasm converted to lactate by the enzyme lactate dehydrogenase (LDH) (Figure 1). The conversion of pyruvate to lactate enables cells to dispose of excess pyruvate and also regenerates NAD+ from NADH, thereby enabling glycolysis and hence energy production to continue. The primary producers of lactate are

skeletal muscle, gastrointestinal tract, brain, heart, skin and erythrocytes.[2] In cells such as erythrocytes and fast-twitch muscle fibres that lack mitochondria, anaerobic glycolysis is the main route of energy production.[3]

Normally a balance exists between the production and clearance of lactate. The lactate produced diffuses out of cells and is transported to other tissues to be used as an energy source. Lactate may be converted back to pyruvate, which can then enter the mitochondria to produce ATP during oxidative phosphorylation. Alternatively, tissues such as the liver and kidneys convert lactate to glucose via gluconeogenesis. The production of lactate by one tissue and its conversion to glucose by another tissue is referred to as the Cori cycle (Figure 2).

Figure 2: The Cori Cycle



The liver and the renal medulla are primarily responsible for the clearance of lactate, metabolizing 50% and 20-30% of the lactate produced respectively.[4] When lactate production is increased, both the liver and kidneys compensate by increasing consumption provided oxygen delivery to these organs remains adequate. This is a saturable process however, and when lactate production exceeds consumption, hyperlactatemia ensues. Hyperlactatemia can also occur if the pathways for lactate consumption are defective. In chronic liver disease, basal clearance of lactate can be maintained; however in acute liver disease, clearance of lactate is reduced resulting in hyperlactatemia. In conditions such as shock, hypoperfusion and hypoxia can not only reduce the ability of the liver to clear lactate, but also result in production of lactate by the liver.[1] Clearance of lactate by the kidneys occurs via increased urinary excretion of lactate, and in particular, via metabolism of lactate to glucose during gluconeogenesis.

Although anaerobic glycolysis produces only 2 molecules of ATP per molecule of glucose, energy production is more rapid than that occurring in the mitochondria during aerobic glycolysis, enabling hypoxic tissues to continue to produce energy. Under anaerobic conditions when glycolysis is the sole source of energy production, hydrogen ions are produced from the continued utilization of ATP and reduction of NAD^+ to NADH (Figure 1). These hydrogen ions are normally consumed during oxidative phosphorylation, so under anaerobic conditions, they continue to accumulate, along with pyruvate and NADH, which ultimately slows glycolysis.[1] The elevation in hydrogen ions is initially titrated by physiological buffer systems, although once these buffers are depleted, acidosis ensues in association with accumulating lactate levels ("lactic acidosis"). Once aerobic conditions are re-established, lactate is either converted to glucose during gluconeogenesis or converted back to pyruvate to enter the Krebs cycle, and the hydrogen ions are neutralized once again by buffering systems, restoring the blood pH to normal.

Reporting lactate levels

Lactate concentrations ([LAC]) are frequently reported in units of mmol/L. Equivalent units are mM and mEq/L. To enable comparison between clinical findings and values reported in different studies, a conversion factor of 0.111 needs to be applied when results are reported as mg/dl (e.g. 1 mg/dl = 0.11 mmol/L). Conversely, to convert mmol/L to mg/dl, a conversion factor of 9.01 is required (1 mmol/L = 9 mg/dl).

Hyperlactatemia versus lactic acidosis

Lactate accumulates when there is an imbalance between production and consumption, either as a result of excessive production, reduced clearance or a combination of both mechanisms. Based on human definitions, hyperlactatemia is defined as a mild to moderate increase in lactate concentration (2 – 5 mmol/L) without concurrent metabolic acidosis. Lactic acidosis is a persistently elevated lactate concentration (usually > 5 mmol/L) in association with metabolic acidosis (pH < 7.35).[5]

Classification of the causes of lactic acidosis

Lactic acidosis has been divided into two broad categories based on the underlying cause. In type A lactic acidosis, tissue hypoperfusion occurs as a consequence of inadequate oxygen delivery or increased oxygen demand.[2] Hypoperfusion and hypoxia are the most common causes of lactic acidosis.[6] Hypovolemic, septic and cardiogenic shock result in systemic hypoperfusion, and local hypoperfusion may be associated with inflammation, vasoconstriction and thromboembolism. Blood loss, severe anemia, and impaired hemoglobin oxygen-carrying capacity, as well as respiratory distress, hypermetabolic states and excessive muscle activity

associated with exercise, seizures and shivering can also cause type A lactic acidosis. Disease states such as sepsis that compromise aerobic energy production and lactate consumption are also implicated. Conversely, type B lactic acidosis occurs in the presence of normal blood oxygen content and blood pressure, and is subclassified into categories of inadequate utilization of oxygen, congenital errors of metabolism, drug or toxin induced, and other miscellaneous conditions including hypoglycemia, thiamine deficiency and severe alkalosis.[1,3] Conditions associated with increased utilization of oxygen or decreased clearance of lactate include sepsis, systemic inflammatory response syndrome (SIRS), neoplasia, liver disease and diabetes mellitus. Drugs or toxins that interfere with oxidative phosphorylation or are associated with lactic acidosis include catecholamines, halothane, morphine, propylene glycol and activated charcoal.[3]

In the critically ill patient, type A lactic acidosis is the most common form encountered, however patients often have components of both types. Although the distinction between types of lactic acidosis may seem academic, it is important to consider the underlying cause when treating lactic acidosis. Treatment often centers around correction of tissue hypoperfusion, the most common cause of lactic acidosis; however, consideration of the underlying cause will help the clinician to differentiate between a poor prognosis based on lack of response to resuscitative fluids and a continued elevation in lactate concentration attributable to a different clinical entity.

Normal lactate levels

Lactate is produced in low concentrations under normal conditions of aerobic metabolism. In people, normal resting values of < 1 mmol/L have been described, corresponding to a lactate production rate of 0.8 mmol/L per kg/hr.[2] Normal resting lactate levels in dogs and cats have been established in a number of studies,[7-10] with normal adult concentrations generally considered to be < 2.0 mmol/L.[5] Higher levels are detected in neonates: 4 day old puppies had the highest [LAC] (3.83 ± 1.38 mmol/L), levels then decreased to approach adult concentrations by 70 days of age (1.80 ± 0.84 mmol/L).[8]

Similar lactate levels have been measured in resting adult horses, with normal lactate concentrations also considered to be < 2.0 mmol/L[11-13] (Table 1). A diurnal variation in [LAC] was documented in neonatal foals and parturient mares, with higher blood lactate levels at night.[14] Similar to dogs, lactate levels are also higher in neonates, however appear to reach adult levels at a much earlier age (by 24 hours).[15] Lactate concentrations of 3.0 ± 0.4 mmol/L have been measured in healthy newborn foals.[16] Lactate concentrations of 4.9 ± 1.02 mmol/L at birth, 2.25 ± 0.6 mmol/L at 12 hours and 0.89 mmol/L at 24 hours were measured in normal neonatal foals[17], with a similar decline over the first 24 hours post partum documented in a more recent study.[18] In this study, lactate concentrations were higher at 20 - 140 minutes postpartum (2.38 ± 1.03 mmol/L) compared to at 24 and 28 hours (1.24 ± 0.33 mmol/L and 1.08 ± 0.27 mmol/L respectively).[18] Clinically, hyperlactatemia in neonatal foals is generally defined as [LAC] > 2.5 mmol/L.[19]

Lactate and the exercising horse

The measurement of blood lactate concentrations in exercising horses is well established.[20] The use of anaerobic pathways for energy production with concomitant production of lactate is considered a normal response to exercise, especially at high speeds. There is a logarithmic increase in lactate concentration as the horse's speed increases, with rapid elevation in lactate concentration once speeds in excess of 7 – 9 m/s are reached. The lactate threshold is defined as the speed associated with this rapid increase in lactate concentration. A number of factors influence lactate threshold, with fitter better performing horses obtaining a higher speed for a given lactate threshold.[20] Treadmill exercise testing is usually used to establish lactate thresholds, with values such as VLa4, the speed at which a [LAC] of 4 mmol/L is reached, used to assess poor performance and to evaluate the effect of training.[21] Alternatively, other tests have been developed and evaluated in the field situation, including derivation of VLa4 via measurement of lactate after two or more exercise steps of different speeds.[22] Such values appear to be correlated with racing performance.[23]

Blood lactate concentrations of 25-30 mmol/L are commonly measured in Thoroughbreds after a race.[20] This physiological hyperlactatemia is quickly resolved by normal blood flow as well as clearance by the liver. The production of lactate with exercise does not directly lead to acidosis. The rapid production of energy in the form of ATP and cycling of NAD+/NADH results in the accumulation of hydrogen ions and acidosis when the normal buffering capacity is exceeded.[24] Similarly, myositis is not a direct result of lactate accumulation within muscle. [24]

Lactate levels have also been measured in sport horses. Lactate concentrations vary depending on the exercise intensity and hence the reliance upon aerobic versus anaerobic metabolism.[25] In endurance horses which have a higher reliance on aerobic energy sources, the increase in [LAC] is minimal compared to in three day eventers (2.7 +/- 0.2 mmol/L and 15.8 +/- 5.8 mmol/L

respectively).[26] Lactate concentrations of 8.5 - 38.5 mmol/L have been reported in three day eventers at the completion of the cross country phase.[27] Similar to race horses, lactate levels have been measured after standardized exercise test in eventers.[28]

Prognostic value of lactate in the critically ill patient

In people, lactate has been established as an important prognostic indicator in the critically ill. Patients with lactic acidosis have a higher mortality rate and are at greater risk for developing multiple organ failure[29], and, as blood lactate concentrations increase, the probability of survival decreases.[30-31] Although a number of studies have shown that lactate concentrations on admission are associated with survival, clearance of lactate, as documented by a decrease in lactate level in response to therapy over 24 hours, has been suggested to be a better predictor of outcome.[31-32]

Similar findings have been documented in dogs admitted to intensive care units. In one retrospective study, dogs with higher lactate levels on admission were more likely to die.[33] Lactate concentration varied depending on the primary disease process, with significantly higher lactate concentrations associated with neurological disease, toxin ingestion and major trauma. However, single admission values did not always predict outcome: some dogs with very high lactate values (› 10 mmol/L) still responded to intravenous fluid and resuscitative therapy, again suggesting that serial lactate levels and changes in response to therapy may be more reliable to determine outcome.[5] In another study of critically ill dogs, admission lactate levels were not significantly associated with outcome; however, hyperlactatemia that did not improve by ≥ 50% within 16 hours was significantly associated with mortality.[34]

An association between lactate concentration and prognosis was recently investigated in a retrospective study of emergency admissions of adult horses to a large referral hospital.[35] For every mmol/L increase in [LAC] at admission, the risk of non-survival increased 7.3 fold. Horses with poor lactate clearance also had a poorer prognosis: for every mmol/L increase in [LAC] at 12, 24, and 48 hours, the risk of non-survival increased by 4-5 fold, and by 50 fold at 72 hours after admission. Horses with small intestinal strangulating lesions had a 37 fold increased risk of death for each mmol/L increase in [LAC] at admission, while horses with colitis had a 20 fold increased risk of non-survival. The authors found increased lactate concentration to be a useful prognostic indicator at admission and, as has been described in people and dogs, sequential measurements as an indicator of lactate clearance revealed decreased survival in the face of persistently elevated lactate concentration.

In horses, mild elevations in lactate concentration are generally considered to be in the range of 2 - 5 mmol/L, marked elevations up to 8 mmol/L, and severe elevations › 8 mmol/L. Regardless of the disease process, it has been suggested that horses with a blood [LAC] › 8 mmol/L will not necessarily have a poor prognosis, but will at least require intensive care.[24] This provides equine practitioners in both the field and the hospital situation with valuable information that can be used in conjunction with other clinical and laboratory findings to formulate a treatment and prognostic plan with owners. The prognostic value of lactate for different clinical entities commonly encountered in equine practice is discussed below.

Anaemia, acute blood loss and the need for blood transfusion

Traditional trigger points for the administration of blood transfusions in horses are based on clinical signs of hypovolemic shock and haematological parameters such as PCV. Heart rate increases in an attempt to maintain cardiac output and circulating blood volume, and associated clinical signs of hypovolemic shock such as tachypnea, weakness and mucous membrane pallor, are well known. Although transfusion is often recommended if 20-30% of the horse's total blood volume is lost acutely,[36] this is typically difficult to quantify. Similarly, other anecdotal recommendations such as an acute reduction in PCV to less than 20%, are neither specific nor sensitive indicators of the severity of blood loss in the first 12 to 24 hours. Rapidly activated compensatory physiological mechanisms such as splenic contraction, greatly influence haematological parameters such as PCV and haematocrit in the acute stages, making these parameters unreliable sole indicators of the need for transfusion.

Lactate has been investigated as an indicator of early acute blood loss and the need for blood transfusion in horses.[37-38] Reduced tissue perfusion and oxygenation lead to a relative increase in anaerobic glycolysis; however hyperlactatemia also occurs as a consequence of cardiovascular dysfunction and catecholamine release.[37] In one study in which 15 – 25% of the total blood volume (~ 8 L) was rapidly removed from healthy horses, [LAC] increased significantly compared to baseline values, and then decreased rapidly after transfusion.[37] In this study, blood [LAC] of 0.5 - 6.7 mmol/L (mean 2.2 ± 1.0 mmol/L) were measured following removal of blood but prior to transfusion. In a recent study, 94% of horses with haemorrhagic anaemia, haemolytic anaemia and

anaemia attributable to erthyropoietic failure had elevated lactate levels.[38] Lactate concentrations between 1.6 - 11.0 mmol/L were measured prior to transfusion (median 4.6 mmol), and ranged from 0.8 – 14.2 mmol/L after transfusion (median 3.2 mmol/L). The greatest degree of improvement in [LAC] was seen in horses with haemorrhagic anaemia. Although it appears that only mild elevations may be evident in some cases, most horses have moderate to severe hyperlactatemia indicating a need for transfusion. Lactate appears to be a useful clinicopathological parameter available for the equine practitioner to assess severity of blood loss and the need for transfusion in conjunction with clinical signs of hypovolemia.

Sepsis, SIRS and endotoxemia

Septicemia is frequently associated with neonates, and regardless of age, endotoxemia is a common clinical entity afflicting many critically ill equine patients. The inflammatory response initiated in response to infection and disease has been widely studied in human and small animal critical care, culminating in the realization that similar inflammatory and anti-inflammatory cascades are activated whether an infectious organism is present or not. Accordingly, new syndromes classified based on this inflammatory response have been adopted in equine critical care fields in recent years.[39] Systemic inflammatory response syndrome (SIRS) is defined as a clinical insult and the presence of 2 or more abnormalities of fever or hypothermia; tachycardia; tachypnea or hypocapnea; and leukocytosis, leucopenia or a left shift (› 10% band neutrophils).[19,39] A variety of clinical insults may initiate this inflammatory cascade including hypoxia, hypovolemia, haemorrhage, tissue ischemia and trauma, with the simplest definition of sepsis being the presence of SIRS and confirmed local or systemic infection.[39]

Hyperlactatemia and lactic acidosis are commonly encountered in patients with sepsis, endotoxemia and SIRS. Although complex, a number of factors contribute to the elevation in [LAC], factors which need to be considered when treating a patient with hyperlactatemia. A horse whose blood lactate level remains elevated despite receiving appropriate intravenous fluid therapy based on the assumption that the underlying cause was hypoperfusion needs to be carefully evaluated. Does the horse have a poorer prognosis because of lack of response to treatment, or have other factors contributed to the hyperlactatemia? Using sepsis as an example, the origin of hyperlactatemia and lactic acidosis is multifactorial: global and local (microvascular) tissue hypoperfusion and hypoxia, impaired hepatic clearance of lactate, hypermetabolism, increased tissue glycolysis due to inflammation, and possibly abnormal mitochondrial function are all likely contributors.[6,40] Pyruvate dehydrogenase, the enzyme responsible for the conversion of pyruvate to acetyl coA, is a key regulator in glucose metabolism. In sepsis, various cytokines induce inhibition of this enzyme. As a result, pyruvate cannot contribute to energy production via the Kreb's cycle, and continues to accumulate in the cytoplasm, thereby providing more substrate for the formation of lactate by LDH. Leukocytes are also significant lactate producers during inflammation, and catecholamines, in particular adrenalin, enhance the activity of the cell membrane Na+K+ ATPase pump, increasing the rate of glycolysis to the extent that the ability to metabolise pyruvate through the Kreb's cycle is exceeded, again leading to increased lactate production.[15] Similarly, endotoxemia can result in hyperlactatemia due to blunting of gluconeogenesis, increased oxygen consumption and marked elevations in pyruvate production.[24] Infusion of endotoxin in horses resulted in an increase in arterial [LAC] from 11.1 mg/dl (1.23 mmol/L) to 40.9 mg/dl (4.54 mmol/L) with concurrent acidosis.[41] Thus the hyperlactatemia observed in horses with gastrointestinal disturbances such as colitis and enteritis, along with other disease processes such as pleuropneumonia, is likely multifactorial and not simply attributable to hypoperfusion and tissue hypoxia.

Foals

Lactate has received a lot of attention in recent years in equine neonatal medicine as a potential indicator of response to treatment and survival. Although commonly used as an indicator of hypoperfusion, hyperlactatemia and lactic acidosis are common in septic neonates with good perfusion, and can often persist despite adequate fluid and vasopressor therapy. The source of lactate in the critically ill equine foal is complex and multifactorial. In septic foals, tissue hypoxia, hypoperfusion, poor liver perfusion and hepatic dysfunction, and inflammatory cells are all likely sources of lactate. Hypermetabolism may be stress induced, associated with adrenalin surges, or cytokine mediated, culminating in increased cellular glucose uptake and lactate production. Increased muscle activity associated with seizures and shivering also contributes, and hyperglycemia can lead to hyperlactatemia through increased lactate production by adipocytes.[42] Lactic acidosis is not limited to the septic foal: elevated lactate levels are also associated with localized trauma and infection, as well as cardiovascular disturbances and organ dysfunction attributed to prematurity and hypoxic ischemic encephalopathy (HIE) [perinatal asphyxia syndrome (PAS)].

In a retrospective study of neonatal foals (‹ 7 days)

admitted to an intensive care unit, arterial [LAC] on admission was associated with survival as well as parameters such as blood pressure, creatinine concentration, bacteremia, and SIRS.[19] A variety of clinical diagnoses were made in these foals including bacteraemia, local infection, PAS, colitis, neonatal isoerythrolysis and prematurity. On admission, the mean arterial blood [LAC] was 6.02 mmol/L (range 0.5 – 17.4 mmol/L). Foals with bacteremia and PAS had higher median [LAC] (7.65 mmol/L and 8.5 mmol/L respectively) than those with colitis (1.7 mmol/L) and local bacterial infections such as pneumonia, omphalitis and septic arthritis (2.0 mmol/L). Foals with septic shock had higher mean admission lactate concentration (11.34 ± 5.6 mmol/L). Admission lactate levels were correlated with mean arterial pressure (MAP) but not with heart rate or PCV: no foal with a MAP ≤ 60 mm Hg had a [LAC] < 7.0 mmol/L, consistent with lactate being a useful indicator of cardiovascular status. Mean [LAC] at admission was significantly lower in foals that survived to be discharged from hospital compared to non-survivors (4.37 ± 0.55 mmol/L and 9.31 ± 0.86 mmol/L). Lactate at 18 - 36 hours after admission was also significantly different between survivors and non-survivors (3.23 ± 0.53 mmol/L and 9.12 ± 0.71 mmol/L respectively). As [LAC] increased at either time point, survival decreased, and foals with lactic acidosis were less likely to survive than foals with hyperlactatemia without concurrent acidosis. Foals with a positive blood culture had higher [LAC] at all time points than those with a negative culture. Similarly, foals with a diagnosis of SIRS had higher mean [LAC] and were less likely to survive to be discharged from hospital.

In other studies investigating lactate as a predictor of survival in neonatal foals, higher admission [LAC] and the persistence of high [LAC] 12 - 36 hours after treatment were also negatively associated with outcome.[43] In Henderson et al's study,[43] a [LAC] of 4.85 mmol/L was established as a cutoff for classifying survivors and non-survivors, a concentration which correctly classified survival in more than 80% of foals. However, foals with positive blood cultures had significantly lower [LAC], a finding which is in disagreement with Corley et al's findings.[19] Foals with a diagnosis of prematurity and HIE had the highest [LAC] but these differences did not persist at 12 - 36 hours. In another study of 225 foals presenting to a neonatal intensive care unit, [LAC] was predictive of survival at a cut-off of 5.5 mmol/L.[44] In this study, the odds of non-survival (either by death or euthanasia) were increased by 23% on admission, 43% at 24 hours and 68% at 48 hours for every 1 mmol/L increase in [LAC], suggesting that foals with early lactate clearance had a better chance of survival. Similarly, a cut-off point of 5.3 mmol/L was useful in predicting non-survival in foals less than 2 weeks of age admitted to a university hospital.[45] Non-survivors had higher venous blood [LAC] on admission, at 12 - 16 hours and at 36 - 40 hours: increasing [LAC] was associated with a 1.65 fold increase in the chance of death. Although septicemic foals had higher [LAC] on admission and at 12 - 16 hours, lactate was not a significant predictor of septicemia, and a statistically significant cut-off point could not be established to predict septicemia.

Based on these studies, it appears that a lactate concentration of ~ 5.0 mmol/L can be used as a predictor of survival, and foals with poor clearance of lactate, as determined by lactate levels that do not decrease in response to therapy, have a poorer prognosis. It is important to remember that this does not mean that every foal with a [LAC] > 5.0 mmol/L will not survive: the author has treated foals with lactate concentrations as high as 21.4 mmol/L that survived. However, a cut-off of ~ 5.0 mmol/L can be useful to the practitioner when discussing prognosis and costs with an owner. These foals will likely require costly intensive care, and certainly the foal that has been treated with intravenous crystalloids, colloids and vasopressor agents as well as other supportive measures but still has an elevated lactate concentration 24 - 48 hours later, has a poorer prognosis. Although umbilical blood lactate concentrations have been documented to have predictive value in human infants with neonatal encephalopathy[46], there are currently no published reports of the measurement of equine umbilical blood lactate and its potential prognostic and predictive value.

Colic

Lactate levels in horses with colic were first investigated over 30 years ago, with high blood lactate concentration identified as a poor prognostic indicator of survival.[12,47] In one study, less than 25% of horses with [LAC] > 101 mg/dl (11.2 mmol/L) survived compared to 93% of horses with [LAC] < 75 mg/dl (8.3 mmol/L).[12] Furr et al developed a severity score in an attempt to predict outcome in horses with colic: blood [LAC], heart rate, abnormal mucus membrane color and peritoneal fluid protein levels were important prognostic indicators.[48] In another study, survival was accurately classified in 93% of horses using a combination of lactate, systolic blood pressure, BUN and PCV.[49] Lactate and PCV had a combined predictive value of 94% in another study of horses with colic: PCV ≤ 43% and lactate ≤ 3.1 mmol/L compared to PCV ≥ 50% and lactate ≥ 5.7 mmol/L differentiated survivors and non-survivors respectively.[50] Further studies have also associated hyperlactatemia with a poor prognosis in horses with colic.[51-52]

Elevated blood lactate concentration in horses with colic can be attributed to a number of factors including dehydration, hypovolemic shock, endotoxemia, hemodynamic compromise leading to tissue hypoxia, and impaired intestinal oxygen delivery due to ischemia. Intraluminal distension and increased intra-abdominal pressure also compromise perfusion. Plasma [LAC] has been shown to be a sensitive indicator of mesenteric ischemia in humans and animals, with a strong association demonstrated between [LAC], gastric necrosis and prognosis in dogs with gastric dilation/volvulus.[53] In that study, preoperative [LAC] was found to be a good predictor of gastric necrosis and prognosis: dogs with a [LAC] › 6.0 mmol/L had a 58% survival rate compared to a 99% survival rate in dogs with [LAC] ‹ 6.0 mmol/L. In a recent retrospective study of 73 horses with ≥360° volvulus of the ascending colon, admission plasma [LAC] was strongly associated with survival.[54] Mean pre-operative [LAC] was significantly lower in survivors (2.98 ± 2.53 mmol/L) than non-survivors (9.48 ± 5.22 mmol/L). Although not measured on all horses, plasma [LAC] 24 hours post-operatively was lower in survivors compared to a limited number of horses which recovered from surgery but did not survive (0.96 ± 0.60 mmol/L and 3.24 ± 3.08 mmol/L respectively). Increased plasma [LAC] was associated with non-survival, with a [LAC] of ‹ 6.0 mmol/L having a sensitivity of 84% and specificity of 83% for predicting survival. Elevated lactate was also associated with non-viability of the colon. No horses with a [LAC] › 10.6 mmol/L survived, findings that are similar to those of other colic studies in which no horses with a blood lactate › 8.6 mM survived,[55] and horses with lactate › 8.3 mM had an extremely low chance of survival.[12]

In addition to blood lactate, peritoneal fluid lactate is also a useful prognostic indicator in horses with colic.[47,56] Peritoneal fluid [LAC] has been measured in horses[11, 56-57] (Table 1) and as blood lactate is always higher than peritoneal fluid lactate in normal horses,[57] the normal blood: peritoneal fluid lactate ratio is › 1. Anaerobic glycolysis secondary to inadequate intestinal perfusion and ischemia results in increased peritoneal fluid and blood lactate levels but not simultaneously. Initially with mild visceral ischemia, peritoneal fluid lactate remains lower then blood lactate, and then peritoneal fluid levels start to rise. With progressive ischemia, peritoneal fluid levels increase more rapidly than blood lactate provided the horse is still hemodynamically stable. Later, when endotoxemia and hypovolemic shock ensue, blood lactate levels sharply increase and approach peritoneal fluid values.

Peritoneal lactate concentration may also aid in distinguishing between horses with nonstrangulating lesions and intestinal ischemia secondary to a strangulating obstruction. In a retrospective study of horses with colic, the mean peritoneal fluid [LAC] was 4.00 ± 4.63 mmol/L, and mean plasma [LAC] 3.00 ± 3.62 mmol/L.[56] In this study, mean peritoneal fluid [LAC] was higher in horses with strangulating obstructions (8.45 ± 5.52 mmol/L) than nonstrangulating lesions (2.09 ± 2.09 mmol/L). Plasma lactate levels were also higher in horses with strangulating lesions. There was no significant correlation between the duration of clinical signs or length of affected intestine and peritoneal or blood lactate levels. Horses that required surgery and an intestinal resection had higher peritoneal and plasma lactate levels. Non-survivors also had higher blood and peritoneal lactate concentrations.

Similar findings were documented in another colic study involving 106 horses.[55] Horses with strangulating lesions had higher blood and peritoneal fluid [LAC] (median 4.90 mmol/L and 12.50 mmol/L respectively) compared to those without strangulating obstruction (median blood 1.20 mmol/L and peritoneal fluid 2.60 mmol/L). Similar to the findings of Latson et al,[56] horses requiring surgery had higher blood and peritoneal [LAC], with the same trend evident in horses with necrotic intestine and those requiring intestinal resection. However, Delesalle et al[55] did see an effect of length of resected intestine on blood [LAC], and peritoneal fluid lactate increased with increasing duration of clinical signs in horses with strangulating obstructions.[55] Both the protein content and gross appearance of peritoneal fluid were correlated with [LAC] in both peritoneal fluid and blood. For every 1 mM increase in blood or peritoneal fluid [LAC], the odds of a horse requiring surgical intervention, intestinal resection, developing ileus and of non-survival increased. Mean blood and peritoneal fluid [LAC] in non-survivors was 6.3 mmol/L and 14.00 mmol/L, and no horses with peritoneal fluid [LAC] › 16.9 mmol/l survived.[55] This study provided further useful prognostic information: peritoneal fluid [LAC] of 1.0, 6.0, 12.0, and 16.0 mmol/L corresponded to a probability of death of [11, 29, 63] and 82% respectively in horses without strangulating obstruction, and to higher probabilities of 25, 52, 82, and 92% in horses with strangulating lesions.

Findings of these studies indicate that peritoneal fluid lactate concentration increases in horses requiring surgery and intestinal resection. Peritoneal fluid lactate may be a better indicator than blood lactate: necrotic intestine increases peritoneal fluid concentrations but is not as well correlated to blood lactate, probably because of other pathological processes that influence blood

[LAC] such as hemoconcentration and endotoxemia. Both blood and peritoneal fluid [LAC] are useful prognostic indicators in horses with colic, and can be measured by equine practitioners even in the field. Blood lactate has additional advantages of providing information on the horse's cardiovascular status, while peritoneal fluid levels may be suggestive of intestinal ischemia. Other clinical, diagnostic and laboratory parameters should be considered however as peritoneal fluid lactate concentration also increases with septic peritonitis and may increase with neoplasia. Horses with blood [LAC] › 8.0 – 10.6 mmol/L, and peritoneal fluid [LAC] › 16 mmol/L will have a poor prognosis for survival.

Lactate and body fluids

Regardless of the fluid type, blood lactate is normally higher than fluid lactate levels. Lactate concentration may increase in body fluids due to a reduction in blood flow, hypoxia, sepsis and production of lactate by white blood cells such as neutrophils and macrophages. The value of peritoneal fluid in horses with colic has been discussed; however lactate concentration in peritoneal fluid and other body fluids are also influenced by other disease processes, notably sepsis.

Peritoneal fluid

Peritoneal fluid lactate concentration has been established as a useful test to aid in the diagnosis of septic peritonitis in dogs and cats.[58-59] In these studies, all patients with septic peritonitis had peritoneal fluid [LAC] that were greater than blood lactate concentrations. A peritoneal fluid to blood lactate difference › 2 mmol/l was considered 100% specific and 100% sensitive to diagnose septic peritonitis.[58] All dogs with septic effusions had a peritoneal fluid [LAC] › 2.5 mmol/L.[59] Elevated peritoneal fluid [LAC] have also been documented in dogs with effusion secondary to intra-abdominal neoplasia[60], attributed to neoplasms utilising anaerobic glycolysis for energy production.

Serum to peritoneal fluid glucose difference › 50 mg/dl, peritoneal fluid pH ‹ 7.3, peritoneal fluid glucose ‹ 30 mg/dl and fibrinogen › 200 mg/dl have been shown to be highly indicative of septic peritonitis in horses.[61] Although studies correlating lactate and septic peritonitis in horses are lacking, results of small animal studies can be extrapolated to the equine patient. Measurement of blood and peritoneal fluid glucose and lactate concentrations and comparison of blood to peritoneal fluid ratios may provide practitioners with rapid information, before cytology and culture results are available. Horses with septic peritonitis would be expected to have elevated peritoneal fluid lactate levels, and a peritoneal fluid to blood lactate ratio › 1.

Pleural Fluid

Lactate levels have been measured in pleural fluid from horses with septic pleuropneumonia and non-septic pleural effusion.[62] Normal pleural fluid lactate levels were 1.63 ± 1.2 mg/dl (0.18 ± 0.13 mmol/L). Pleural fluid lactate levels were higher than blood lactate concentrations in horses with septic effusions. Similar to peritoneal fluid measurements in septic peritonitis, low pleural lactate levels make sepsis unlikely, and elevated levels are suggestive of septic effusion. Pleural fluid lactate was elevated (2.23 mmol/L) in a horse with thoracic neoplasia, [63] and a horse with pleuritis (4.83 mmol/L).[64]

Pericardial Fluid

In a study of dogs with septic pericarditis, 61% had hyperlactatemia, and all affected dogs had pericardial fluid concentrations greater than blood lactate concentration.[65] Pericardial fluid lactate also increases in dogs with neoplasia; however there is some overlap with non-neoplastic disease. Pericardial fluid lactate was 22.42 mmol/L and blood lactate 1.10 mmol/L in a horse with pericarditis caused by Corynebacterium pseudotuberculosis.[64]

Synovial Fluid

Synovial fluid lactate levels have been investigated in people, with the identification of low lactate levels considered as a criteria to eliminate a diagnosis of septic arthritis with a negative predictive value of 98%.[66] However in people, synovial fluid lactate levels can also increase in non septic conditions such as rheumatoid arthritis.[67] A synovial fluid [LAC] › 7.2 mmol/L is considered consistent with bacterial infection in people.[68-69] In an experimental model of infectious arthritis in horses, synovial fluid [LAC] increased to › 4.9 mmol/L from normal levels of ‹ 3.9 mmol/L in 66% of horses.[70] Synovial fluid [LAC] also increased in control joints injected with saline, however levels remained below 4.4 mmol/L. Synovial fluid [LAC] was considered more diagnostic in the acute rather than chronic stages. Synovial fluid lactate should not be used as the sole diagnostic parameter to diagnose septic arthritis, however markedly elevated lactate levels should raise suspicion of sepsis.

Cerebrospinal Fluid

As lactate does not cross the blood brain barrier, cerebrospinal fluid lactate concentration is independent of blood [LAC] provided the blood brain barrier is intact and not inflamed. Elevated CSF lactate levels have been documented in people with head injuries, as well as

viral and bacterial meningitis.[71] Mildly elevated blood lactate concentrations were documented in a small group of horses with traumatic brain injury (median 2.6 mmol/L, range 1.0 – 13.4 mmol/L), and may have been due to hypoperfusion, seizures, catecholamine surges, or high muscle activity.[72] The usefulness of CSF lactate levels in diagnosing disorders in horses remains to be determined.

Lactate: Collection of samples, sample handling and method of analysis

Sampling site, method of collection and sample handling can all influence lactate levels. Where the blood is collected from causes some variation in [LAC]. Peripheral venous samples are thought to reflect regional lactate kinetics, and arterial samples may be a better reflection of systemic lactate levels.[5] There was a small but significant difference in [LAC] between samples obtained from different sites in healthy adult dogs.[73] Cephalic vein samples had a higher mean lactate level (1.57 ± 0.47 mmol/L) than femoral artery samples (1.43 ± 0.52 mmol/L) and jugular venous samples (1.25 ± 0.49 mmol/L), although this difference was not considered to be clinically significant. In five foals between 30 - 46 hours of age, jugular venous [LAC] and dorsal metatarsal artery [LAC] were 2.18 ± 0.35 mmol/L and 2.17 ± 0.49 mmol/L respectively.[74] Such results lend further support to the conclusions drawn from similar studies in dogs[73] and humans[75] that any difference between arterial and venous lactate levels is unlikely to be of clinical significance.

Blood samples for lactate measurement should not be taken directly from intravenous catheters, as intravenous fluids containing lactate (e.g. Lactated Ringers Solution) that have been inadequately cleared from the catheter can falsely increase results.[76] Similarly, fluids containing 5% dextrose may also increase lactate levels.[77] Blood collection from difficult patients requiring excessive restraint and prolonged venous occlusion has been proposed to result in mild increases in lactate levels. In stressed cats, a transient 10 fold increase in [LAC] was documented.[10] Muscle activity in shivering animals may also increase lactate levels, and in the equine patient, it has been recommended that caution be used in restraint as exercise and struggling can cause transient increases in [LAC].[15]

Sample handling is important and perhaps has the greatest effect on lactate levels. Red blood cells continue to produce lactate after the blood sample has been collected.[9] As lactate production may continue by as much as 20% during each hour of storage at 25°C, it is recommended that samples are analyzed rapidly (preferably within 5 minutes although up to 30 minutes is okay[78]), or temporarily stored on ice but this does not completely arrest lactate production.[5] If sample analysis is likely to be delayed, plasma should be separated from red blood cells, or samples placed on ice to limit production of lactate by red blood cells in vitro.[1] Use of haemolysed samples is not recommended.

Lactate concentrations, specifically L-lactate, are measured using one of two methods: amperometry and spectrophotometry (colorimetry). Laboratory-based blood gas analysers use enzymatic amperometry: lactate oxidase converts lactate to pyruvate and hydrogen peroxide, the latter is oxidized on an electrode to produce a current that is proportional to and hence an indirect measure of the sample lactate concentration.[3] Other blood chemistry analysers, including some hand-held lactate analysers, use enzymatic spectrophotometry. Another by-product of the oxidation of lactate to pyruvate by the enzyme lactate oxidase is NADH. The NADH produced is detected in proportion to the lactate in the sample by reflectance photometry which measures spectrophotometric absorption.

Which blood tubes should be used? This is largely dependent on how the sample will be analysed, which in turn requires knowledge of the methodology the analyser to be used incorporates. Regardless of the methodology, plasma and whole blood samples are preferred over serum, but EDTA samples appear to be unsuitable. Laboratory based blood gas analysers utilize enzymatic amperometry. Anticoagulants interfere with lactate measurement by these analysers, so whole blood samples should be used. This necessitates either immediate analysis, which is impractical unless based at a university, or placement of samples in either lithium heparin tubes or heparinised syringes (pretreat syringe with heparin then evacuate prior to taking blood). The use of sodium fluoride or sodium citrate tubes is usually not recommended for amperometry analysis.[79] Most chemistry analysers use spectrophotometric analysis. These samples need to be collected into sodium fluoride or sodium citrate tubes which inhibit glycolytic enzymes, and placed in ice to decrease lactate production by red blood cells.[9] If you intend to have lactate analysis performed by an outside laboratory, it is wise to check how they prefer to receive the samples. With the IDEXX Vet Test® chemistry analysers, manufacturer's recommendations are that fluoride oxalate or lithium heparin plasma samples are used, but if in lithium heparin, plasma should be analysed within 5 minutes or plasma separated from red blood cells.

Hand held lactate analysers

Point-of-care (POC) hand held lactate meters were initially utilized by human athletes for rapid lactate measurement during exercise, and have become increasingly popular in human and veterinary critical care. These analysers enable practitioners to obtain timely results without the need to transport blood samples to an outside laboratory, thereby eliminating the delay between taking the sample and obtaining a result. This is important as treatment decisions in critically ill patients are time sensitive and often serial measurements are required to evaluate response to treatment and clinical progression or deterioration. A number of POC analysers measure lactate by amperometry (i-STAT®[b], Lactate Pro®[c], Lactate Scout®[d]). Accordingly, whole blood samples should be used, and either analysed immediately, placed in lithium heparin tubes or drawn using heparinised syringes. For the spectrophotometry based POC monitors (Accutrend®[e], Accutrend Plus®[f], Accusport®[g]), whole blood or plasma can be used and samples placed in sodium fluoride tubes, although lithium heparin tubes are also suitable. In both the hospital and field situation, drawing blood into heparinised syringes is simple and practical, and samples can then be analysed using most POC monitors.

The Accutrend® and Accusport® analysers operate using a similar mechanism. An unmeasured drop of blood (approximately 25 ®[l]) is placed on a strip comprising 4 layers with the bottom layer simply a support layer.[80] The top layer is a protective mesh where the blood is applied, and the second layer is a glass fibre layer which separates red blood cells from the plasma. The plasma then diffuses to the third layer where a chemical reaction with lactate oxidase occurs, resulting in a colour change proportional to the [LAC] in the sample. The colour change is measured by use of reflectance photometry which is translated into a lactate value that is displayed on the screen. The meter measures [LAC] in plasma, and has an internal conversion factor which enables calculation and display of lactate concentration as a whole blood level. The measuring range of the Accutrend® reported as 0.8 – 22 mmol/L for whole blood and 0.7 – 27 mmol/L for plasma.[1] The Lactate Pro® and Lactate Scout® analysers use an amperometric reaction, with 5 µl of blood automatically drawn from the syringe into the test strip. The blood reacts with lactate oxidase and potassium ferricyanide producing a current which is measured and reported as a lactate value.[81] The measuring range reported for the Lactate Pro® analyser is 0.3- 25 mmol/L, and for the Lactate Scout® analyser 0.25 – 25 mmol/L. The i-STAT® analyser uses a similar methodology without collecting an automated sample and uses platinum instead of potassium ferricyanide.

A number of POC analysers have been evaluated in both small animals and horses. Measurements from 4 hand held POC lactate meters (Lactate Pro®, Lactate Scout®, Accutrend® and i-STAT®) and a laboratory analyser were in agreement in a study in dogs using lithium heparin samples.[82] The POC meters tended to overestimate lactate levels when the concentration was low, and underestimate levels at high concentrations, however the difference was small. In dogs, the precision of the Accutrend® analyser was good when the sample was 25µl but not smaller (25 µl equates to a "hanging drop" of blood).[34] The Lactate Pro® analyser has been evaluated in horses, with good correlation with a laboratory based blood gas analyser.[83] The Accusport® analyser was also accurate in horses when compared to a chemistry analyser using heparinised[84] and sodium fluoride samples[85], and when compared to the iSTAT® analyser.[86] Good results were also obtained when the iSTAT® was compared to in house blood gas analysers.[87]

In humans, high PCV results in lower reported [LAC] by POC meters, especially when lactate levels are high. The Accusport® lactate meter has been shown to be accurate in horses between 0.8 – 20 mmol/L, but may underestimate results when lactate concentrations are › 10 mmol/L or PCV › 53% in heavily exercised horses.[88] Tennent-Brown et al[89] evaluated the use of the Accutrend® meter compared to a laboratory based analyser in horses, and investigated the effect of PCV and TS. Horses with a PCV ≥ 40% had a significantly higher blood [LAC] compared to horses with a PCV ‹ 40% (mean 3.9 ± 4.0 mM and 1.9 ± 2.4 mM respectively). Similarly, horses with a [LAC] ≥ 5 mM had a significantly higher PCV (mean 51 ± 13%) than horses with a [LAC] ‹ 5 mM (mean PCV 40 ± 8%). More accurate results were obtained when using plasma rather than whole blood samples; however the authors found that using the Accutrend® monitor in "blood' rather than "plasma" mode achieved best concordance with the laboratory based analyser regardless of whether a whole blood or plasma sample was used. This is in contrast to earlier recommendations by Evans et al[88] who recommended using the monitor on plasma mode as the internal conversion factor in the meter which calculated "whole blood" values from the actual lactate level measured in plasma was based on human data and was not thought to be suitable for horses.

Hand-held POC analysers have also been validated for use on peritoneal fluid samples in horses. Saulez et al[52] compared both blood and peritoneal fluid samples (both

in sodium fluoride tubes) from 56 horses with colic using an in house blood gas analyser and the iSTAT® analyser. The POC monitor tended to underestimate [LAC] when lactate was ‹ 5 mmol/L in blood samples and ‹ 2 mmol/L in peritoneal fluid samples. Results were more variable when blood lactate was › 5 mM, and the variability in peritoneal fluid lactate level measured also increased as the lactate concentration increased, i.e. the iSTAT® analyser tended to underestimate lactate levels especially in the higher ranges. Delesalle et al[55] evaluated the Accusport® analyser on blood and peritoneal fluid samples (both in lithium heparin) from 20 healthy horses and 106 horses with colic. Below a blood [LAC] of 13 mM and a peritoneal fluid lactate of 20 mM, the difference between lactate measured by the Accusport® analyser and a laboratory based analyser was small.

Treatment

In practice, lactate concentrations are helpful as trigger or end points for therapy. It is important to remember that lactic acidosis is not a disease in itself but rather a consequence of an underlying process. As hypoperfusion is the most common cause of hyperlactatemia and lactic acidosis, initial treatment of a patient with elevated blood lactate concentration usually involves intravenous fluid therapy.[90] This does not mean that all horses with hyperlactatemia require IV fluids: a thorough clinical examination is vital to rule out fluid retention or fluid overload such as due to congestive heart failure or anuric renal failure, cases in which high volumes of IV fluids may be contraindicated. Using 6 adult horses with acute colic, Fielding et al evaluated the use of venous blood [LAC] to guide fluid therapy.[90] Horses were administered a 20 ml/kg bolus of LRS (~10 L) over 1 hour, and lactate, PCV and TP measured before and after fluid administration. In 3 horses, lactate levels continued to rise following the IV fluid bolus, however these horses all had surgical lesions or gastrointestinal rupture. The authors suggested that if lactate levels are › 2 mmol/l or there are other clinical signs of hypovolemia, a fluid bolus should be administered and the lactate level rechecked. If lactate is decreasing, horses can be changed to a maintenance IV fluid plan. If levels are unchanged or continuing to increase, additional boluses may be administered however the horse should be carefully re-evaluated or referred. In practical terms in the field situation, if the horse's blood [LAC] is › 4 - 5 mmol/L and does not decrease in response to an IV fluid bolus, or if the lactate concentration is › 8 mmol/L, the horse should be referred to a hospital. Such horses are likely to require prolonged intensive care and intravenous therapy in the form of both crystalloids and colloids, and possibly surgical intervention for the colic patient.
Bicarbonate supplementation is often required in patients with significant metabolic acidosis, especially foals. However, sodium bicarbonate is not beneficial in treating most cases of lactic acidosis.[91] In the acidotic patient, blood pH improves following improvement of perfusion, as clearance of lactate by the liver is accompanied by a concurrent increase in bicarbonate production by the liver[92] and has a net alkalising effect.

Treatment – what about lactated ringers solution (LRS)?

Lactated Ringers Solution (Hartmanns®[h], LRS) contains 28 mmol/L sodium lactate as an equal mixture of L-lactate and D-lactate. Following intravenous infusion of LRS, the lactate in this fluid is metabolised to glucose or oxidised to form carbon dioxide and water.[1] Although D-lactate is not metabolised, this isomer does not usually cause an increase in blood [LAC].[77] Further, administration of lactate in LRS does not contribute to acidosis as it exists as a sodium salt rather than "hydrogen lactate".[15] In humans and dogs given a bolus of 15-20 ml/kg of LRS, there was no significant change in plasma [LAC].[77,93] However, it has been suggested that care be taken in administrating LRS to patients with impaired hepatic and renal lactate clearance[15] as dogs with lymphoma showed a transient increase in lactate levels following a 6 hour constant rate infusion of LRS.[94] Suggested alternatives for patients with impaired hepatic clearance are fluids that contain acetate rather than lactate (e.g. Plasma-Lyte®[i] or Normosol®[j]).[15]

Lactate – take home messages

Lactate concentration has been demonstrated to be a useful prognostic indicator in horses, consistent with findings in human and small animal critical care. Although cut-off points associated with a poor prognosis have been established in some studies, care should be taken in using lactate as the sole indicator of survival. A horse or foal with a lactate concentration exceeding these cut-off points will not necessarily die; rather these values can be used as an indication of the need for intensive therapy and as an aid in formulating a treatment plan and prognosis. Hand-held lactate analysers can provide rapid results, thereby assisting practitioners to make informed recommendations to owners related to the anticipated costs of intensive care or surgery. In horses with colic, blood lactate concentrations › 8 - 10 mmol/L are associated with a poor prognosis, and can be a useful indicator of the need for surgery, especially when peritoneal fluid lactate concentration is measured concurrently. Lactate is a sensitive indicator of blood loss, and sequential measurements can be used to guide the need for transfusion, e.g. a horse with a lactate concentration of 3 mmol/L but stable cardiovascular status may be monitored for longer, compared to a horse

with a lactate concentration of 10 mmol/L and marked tachycardia which will require more rapid intervention and likely transfusion. Although blood lactate › 5.0 mmol/L is associated with a poor prognosis in foals, this cut-off point can also be used as a further indicator for the need of intensive care and perhaps referral. Lactate is easy to measure and provides useful and rapidly available information for the equine practitioner, in both hospital and field situations.

FOOTNOTES

a. i-STAT, Heska Corporation, Colorado, USA
b. Lactate Pro, Arkray, Minnesota, USA
c. Lactate Scout, SensLab, Leipzig, Germany
d. Accutrend, Roche Diagnostics, Basel, Switzerland
e. Accutrend Plus, Roche Diagnostics, Basel, Switzerland
f. Accusport, Boehringer Mannheim, Germany
g. IDEXX Vet Test Chemistry Analyser, Idexx Laboratories, Rydalmere, NSW
h. Hartmanns, Baxter Healthcare, Toongabbie, NSW
i. PlasmaLyte, Baxter Healthcare, Toongabbie, NSW
j. Normosol-R, Abbott Laboratories, Illinois, USA

Table 1
Reference equine blood and peritoneal fluid lactate concentrations

Sample	Age	Mean (mmol/L)	Range (mmol/L)
Blood	ADULT	1.0 ± 0.3[11]	0.7 – 1.7[11]
			0.4 – 1.33[12]
			0.28 – 1.72[13]
		1.04 ± 0.26[41]	0.57 – 1.53[41]
			0.37 – 1.43[56]
		0.59 ± 0.22[55]	
	Lactating mare	0.59 ± 0.17[14]	
	Parturient mare	1.82 ± 0.77[14]	
	FOAL Newborn (‹ 24 hrs)	3.0 ± 0.4[16]	
	Neonate: At birth	4.09 ± 1.02[17]	
	12 hrs	2.25 ± 0.6[17]	
	24 hrs	0.89[17]	
	Neonate: 20 – 140 mins	2.38 ± 1.0[18]	
	24 hrs	1.24 ± 0.33[18]	
	48 hrs	1.08 ± 0.27[18]	
	Neonate: 30 – 46 hrs	2.18 ± 0.35[74]	
	Foal: 1 week old	1.03 ± 0.08[14]	
	13 weeks old	2.49 ± 0.22[14]	
	1-6 month old		0.9 – 1.65[13]
Peritoneal fluid	ADULT	0.7 ± 0.2[11]	0.4 – 1.2[11]
		0.66 ± 0.43[41]	
		0.49 ± 0.27[55]	
		0.6 ± 0.19[56]	0.22 – 0.98[56]
			0.30 – 1.47[57]

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