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Culture-Positive Sepsis in Neonatal Camelids: 21 Cases

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Background: There is limited literature on neonatal bacterial sepsis in New World (NW) camelids.

Hypothesis: Bacterial culture–positive crias have clinical differences based on the specific bacterial genera isolated.

Animals: Bacterial culture–positive NW camelid crias <21 days of age from 1990 to 2005 were included.

Methods: Historic physical examination and cliniopathologic data were retrieved from medical records as were the identity and antibiograms of bacterial isolates. Cases were categorized by outcome (survival versus nonsurvival) and type of sepsis (gram-negative or gram-positive). Kruskal-Wallis and chi-square testing were used to evaluate differences between groups.

Results: Twenty-one crias met the inclusion criteria. Median age was 2 days. Failure of passive transfer was common. There were few differences identified on the basis of outcome or type of sepsis. Crias without gastrointestinal or central nervous system involvement survived in greater numbers. Forty-six percent of isolates were gram-positive. The most common isolates were the following: *Escherichia coli*, *Enterococcus* spp., *Listeria monocytogenes,* and *Citrobacter* spp. Overall survival was 67% (14/21).

Conclusions and Clinical Importance: Crias with sepsis do not appear to present with major biochemical, hematologic, or blood gas abnormalities, potentially complicating diagnosis. Affected crias may not have localizing signs at presentation and are not usually febrile, although hypothermia, tachypnea, and tachycardia are relatively common. Total protein concentration was not a substitute for immunoglobulin G measurement in septic crias in this study. Familiarity with the clinical presentation and common pathogens isolated should improve early recognition and treatment and ultimately outcome of crias with sepsis.

Key words: Alpaca; Bacteremia; Infection; Llama.

Sepsis is a well-documented neonatal clinical problem in many domestic species, having substantial mortality and morbidity and commonly associated with failure of passive transfer (FPT) in both cattle and horses.[1,2] Sepsis also is reported as a complication or comorbidity of other perinatal problems such as dystocia, placentitis, prematurity, dysmaturity, or neonatal hypoxia.[3] Neonatal sepsis in both calves and foals may have a rapid onset and progression and may be fatal. Early diagnosis and treatment of neonatal sepsis have been shown to improve outcome.[4,5]

New world (NW) camelids have become increasingly popular in North America, and large animal veterinarians now treat NW camelids that have diseases similar to those found in other large animals. There is limited literature describing common conditions of neonatal camelids with few reporting specifically on bacterial infection in neonatal NW camelids.[6–11] The purpose of this retrospective study was to provide additional clinical information regarding culture-positive sepsis in neonatal NW camelids to improve recognition and treatment of this condition and provide information regarding prognosis.

Materials and Methods

Blood culture submissions to the Microbiology Unit at the New Bolton Center Kennet Square, PA, between January 1, 1990, and December 31, 2005, were screened to identify positive blood cultures in NW camelids of <21 days of age at presentation. Additionally, all medical records of NW camelids <21 days of age at presentation that received a clinical diagnosis of sepsis by the attending clinician were reviewed, and crias were included if either a positive blood culture or positive culture from a postmortem sample was obtained during the patient's hospitalization. Data were collected from the records, including historic information (eg, age, gestational duration, history of peripartum disease, dystocia, time from birth to sucking from dam, treatments given on the farm, and presenting complaint) and were recorded for each cria. Also recorded were admitting temperature, heart rate, and respiratory rate. It was noted if the cria was standing, sternally recumbent, or laterally recumbent for the initial examination. Hematologic and clinical chemistry findings, including blood gas and lactate measurements if performed, also were extracted from the medical record. Reference ranges for hematologic and clinical chemistry values Tables 1, 2 were obtained from the relevant veterinary literature because reference ranges had not been established for normal crias in our laboratory at the time of the study.

Physical examination findings were divided into body system abnormalities to further characterize problems identified in each animal. If the animal developed any of the following signs during hospitalization, it was recorded as dysfunction in that body system:

(1) Gastrointestinal dysfunction: intolerance to feeding (signs of gastrointestinal pain, reflux), diarrhea, colic, or ileus.
(2) Musculoskeletal dysfunction: infection found in 1 or more joints.
(3) Central nervous system dysfunction: profound depression, seizure activity, or ataxia.
(4) Pulmonary dysfunction: abnormal blood gas results, dependence on intranasal oxygen, or abnormal respiratory rate or pattern.
(5) Renal dysfunction: abnormal urinalysis, plasma creatinine concentration, blood urea nitrogen concentration, or urine output.
(6) Metabolic dysfunction: presence of hyperlipemia, hypoglycemia, or hyperglycemia.
(7) Cardiac dysfunction: hypotension, bradycardia, or tachycardia,
(8) Failure of passive transfer (FTP): measured immunoglobulin G (IgG) concentration <900 mg/dL.[9,10] History of additional colostrum or intravenous (IV) plasma administration was interpreted as suggestive of previous FPT. These

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crias were not included in statistical comparisons of crias with and without FPT or other statistical evaluations involving IgG plasma concentration.

Treatments administered were recorded for each patient. If the animal did not survive, the postmortem examination report was reviewed to identify abnormal organ systems.

Blood cultures usually were obtained in a sterile fashion before initiation of antimicrobial therapy, but in some cases, antimicrobial treatment had been administered before referral. Blood obtained for culture was injected into BBL Septi-check[a] blood culture bottles using sterile technique. Microbial growth was monitored daily for 7 days. Specific microbial identification was performed utilizing standard microbiologic techniques, and antimicrobial sensitivity was determined. Microbiologic samples obtained at postmortem examination did not necessarily have antimicrobial sensitivity testing performed on the isolate according to the existing protocol for the laboratory. Cases were categorized by outcome (survival to discharge versus nonsurvival to discharge) and type of sepsis (gram-negative or gram-positive) for purposes of comparison and also by specific bacterial isolate. Additional comparisons were made between crias with specific bacterial isolates and the remaining crias if the genus of bacteria was isolated in 3 or more instances.

Statistical analysis was performed using a commercially available statistical software package.[b] Nonparametric testing was used because of the small sample size and non-Gaussian data distribution. Data are reported as median (25th–75th percentile). Differences between groups were examined with Kruskal-Wallis testing. Chi-square testing was used to evaluate categoric data differences. Significance was set at $P \leq .05$.

Results

Twenty-one cases met the inclusion criteria. No cases were found before 1995. Case numbers for subsequent years were the following: 1995 (1), 1999 (1), 2000 (5), 2001 (2), 2002 (3), 2003 (7), 2004 (1), and 2005 (1).

Signalment and Historical Information

There were 6 llama crias and 15 alpaca crias. Four llama and 10 alpaca crias survived to discharge. Not all data were available for all cases. There were no differences found between llama and alpaca crias for any analyzed variable. The median age at the time of admission was 2 (0.6–5.0) days with a range of 6 hours to 18 days (Table 1). Sixteen crias were female and 5 were male. Presenting complaints included weakness (n = 7), not nursing (n = 5), prematurity (n = 2), diarrhea (n = 2), and a single complaint each of apparent blindness, hypothermia, regurgitation, anuria, and upper airway noise. Gestational duration was documented in 16 crias: 6 were premature (<320 days), 8 were of normal gestation (320–365 days), and 2 had prolonged gestation (>365 days). Premature delivery was reported, but no gestational duration was provided, in 2 additional cases. History of antenatal disease, such as illness of the dam or problems during parturition, was present in 4 of 19 cases where perinatal history was available. Dystocia was reported in 3 of 13 records where parturition was described. Treatments before admission included antimicrobials (n = 5), additional colostrum (n = 4), and IV plasma (n = 3).

Table 1. Reference ranges for hematologic indices.

Parameter	Adult Camelid[a]	Neonatal Llamas[b]
Packed-cell volume (%)	33 ±6	24–35
Total protein (g/dL)	4.7–7.3	3.9–6.6
White blood cell ($10^3/\mu L$)	14.0 ± 3.0	7.1–19.4
Neutrophil ($10^3/\mu L$)	56–87%	1.1–14.6
Band neutrophil ($10^3/\mu L$)	0–4%	0.0–0.5
Lymphocyte ($10^3/\mu L$)	2–22%	1.7–4.7
Fibrinogen (mg/dL)	327 ± 96	NA

NA, not available.
[a] Source: Fowler.[12]
[b] Neonatal: <30 days of age. Source: Fowler and Zinkl.[13]

Physical and Clinicopathologic Variables

Fourteen crias survived to discharge, whereas 7 died or were euthanized during hospitalization. Median values for heart rate and respiratory rate were above the published upper limit of the normal range; there was no association of rectal temperature, heart rate, or respiratory rate with either outcome or categorization of sepsis as gram-negative or gram-positive (Table 1). Eleven crias were standing at admission and 8 survived. Three crias were able to maintain sternal recumbency and 2 of them survived. The remaining 7 crias presented in lateral recumbency and 4 of them survived. There was no association between ability to stand at admission and outcome.

No difference was found between outcome groups (survival versus nonsurvival to discharge) and admission plasma biochemistry abnormalities except plasma potassium concentration, which was larger in nonsurvivors ($P = .032$) and lower than the reported normal range for healthy llama crias in all groups except nonsurvivors[13] (Tables 2, 3). Cases in which gram-negative sepsis was identified had lower median admission neutrophil counts than did cases with gram-positive sepsis ($P = .017$) (Table 2). Six crias had FPT (IgG <900 mg/dL) at presentation; 3 crias received IV plasma and 2 colostrum supplementation before referral, suggestive of previous FPT. There were no differences (4.8 versus 4.6 g/dL, $P = .69$) in total protein concentration between crias with documented FPT (n = 6) and those with IgG concentration >900 mg/dL at presentation (n = 6).

A suck response was present in 14 crias at admission. Abnormal physical examination findings included angular limb deformity (n = 3), abnormal umbilicus (n = 1), injected mucous membranes (n = 13), mucous membrane petechia or erythema (n = 3), poor pulse pressure (n = 5), and diarrhea (n = 5). No association was found between abnormal physical examination findings and outcome. Recorded sites of organ dysfunction were metabolic (n = 13), gastrointestinal (n = 11), respiratory (n = 11), ophthalmologic (n = 10), renal (n = 9), cardiovascular (n = 9), central nervous system (n = 9), hepatic (n = 3), and musculoskeletal (n = 2). Eleven crias either had documented FPT (n = 6) or had been treated for FPT before admission (n = 5). Gastrointestinal dysfunction was identified most commonly in crias with gram-positive infection (9/11, $P =$

Table 2. Reference ranges for clinical biochemistry and blood gas findings.

Parameter	Adult Camelid[a]	Adult Camelid[b]	Neonatal Llamas[c]
Glucose (mg/dL)	120–132	86–163	94–170
Creatinine (mg/dL)	1.4–1.7	0.8–2.8	1.1–2.9
Sodium (mmol/L)	145–151	148–158	148–155
Chloride (mmol/L)	112–119	98–120	101–116
Potassium (mmol/L)	4.2–4.7	3.6–6.2	4.6–5.9
Calcium (mg/dL)	8.8–9.6	7.6–10.9	9.4–10.6
pH		7.35–7.5	
PCO_2		39–45	

NA, not available.
[a] Source: New Bolton Center Clinical Laboratory; based on Veterinary Reference Guide for Kodak EKTACHEM Products.[14]
[b] Source: Fowler.[12]
[c] Neonatal: <30 days of age. Source: Fowler and Zinkl.[13]

.021), whereas crias affected by respiratory (9/11, P = .021), metabolic (9/13, P = .016), and ophthalmologic (7/10, P = .032) dysfunction were more commonly identified as having gram-negative infection. Crias without gastrointestinal disease were more likely to survive to discharge (P = .032), as were those without central nervous system disease (P = .001).

Microbiology Results

Twenty of 21 crias had at least 1 positive blood culture, 2 crias had 2 positive blood cultures, and 1 cria was culture-positive at postmortem examination only. Of the 20 crias with positive antemortem blood culture results, 18 were positive on a single blood culture sample, 1 was culture-negative on day 1 with a positive culture on day 2 of hospitalization, and 1 cria had 2 positive blood cultures (1 at admission and 1 later in its hospitalization). One cria had a postmortem diagnosis of sepsis and a positive postmortem culture but 2 negative blood cultures before euthanasia. Of 21 crias, 18 had a single organism identified, 2 animals had 2 organisms identified on a single culture, and 1 animal had different single organisms identified in each of 2 consecutive cultures. Cultures resulted in isolation of gram-negative organisms on 13 occasions and gram-positive organisms on 11 (Table 4). The most commonly isolated organisms were *Escherichia coli* (n = 4), *Enterococcus* spp. (n = 4), *Listeria monocytogenes* (n = 3), and *Citrobacter* spp. (n = 3).

Only 50% (2/4) of animals from which *E coli* was isolated survived (Table 4). Crias with *E coli* sepsis had significantly increased median lymphocyte counts (2.8 versus 1.6 $\times 10^3/\mu L$, P = .038) and decreased median chloride concentration (108 versus 116 mmol/L, P = .042) compared with crias with other infections. All 4 crias with *Enterococcus* spp. infections survived and had median admission respiratory rates that were significantly slower (27 versus 40 beats per minute [bpm], P = .038) than those of others. Only 1 of 3 (33%) crias with culture-confirmed *L monocytogenes* infection survived. Crias with listeriosis had median admission respiratory rates that were significantly higher (60 versus 34 bpm, P = .042). Two of the 3 crias with *Citrobacter* spp. infection survived. Crias with *Citrobacter* spp. infection had lower median rectal temperatures at admission (98.2 versus 101.2°F, P = .027). *Citrobacter* spp.–infected crias also had lower median total protein concentrations (4.2 versus 5.0 g/dL, P = .038), lower median white blood cell counts (1.2 versus 10.5 $\times$ $10^3/\mu L$, P = .021), lower median neutrophil counts (1.4 versus 8.6 $\times$ $10^3/\mu L$, P = .032), and lower median glucose concentrations (22 versus 120 mg/dL, P = .022).

Table 3. Temperature, heart rate, and respiratory rate of culture-positive septic neonatal crias at admission. Data are presented as median (25th–75th percentile).

Parameter	Reference Range[a]	Overall	Nonsurvivors	Survivors	Gram-Positive	Gram-Negative
Rectal temperature (°F) (n = 21)	100–102.5	100.7 (98.6–101.9)	101.2 (96.0–101.6)	100.4 (98.7–102.0)	100.6 (99.9–101.7)	100.7 (98.2–102.1)
Heart rate (beats/min) (n = 20)	60–90	120[b] (113–153)	124[b] (103–178)	120[b] (110–138)	20[b] (113–151)	124[b] (113–152)
Respiratory rate (breaths/min) (n = 19)	10–30	40[b] (28–50)	40[b] (26–60)	34[b] (28–43)	40[b] (30–60)	34[b] (28–40)
Age at admission (days) (n = 21)	NA	2.0 (0.6–5.0)	5.0 (2–13)	1 (0.5–4.3)	2.9 (0.4–8.8)	2.0 (1.0–5.0)

NA= not available.
[a] Normal values for neonatal camelid.[12]
[b] Outside of published normal range.

Table 4. Hematologic indices of culture-positive septic neonatal crias at admission. Data are presented as median (25th–75th percentile).

Parameter	Reference Range[a]	All Crias	Nonsurvivors[b]	Survivors[b]	Gram-positive[b]	Gram-negative[b]
Packed-cell volume (%) (n = 20)	24–35	32 (30–37)	33 (31–38)	32 (30–36)	33 (30–35)	32 (30–38)
Total protein (gm/dL) (n = 19)	3.9–6.6	4.6 (4.5–5.2)	5.0 (4.6–6.5)	4.6 (4.4–5.1)	4.6 (4.4–5.2)	5.0 (4.5–5.2)
White blood cell ($10^3/\mu L$) (n = 21)	7.1–19.4	11.6 (5.1–14.6)	10.6 (4.5–31.2)	10.2 (5.5–14.6)	12.3 (8.0–27.2)	5.7 (3.7–12.8)
Neutrophil ($10^3/\mu L$) (n = 20)	1.1–14.6	9.1 (3.2–12.1)	8.5 (3.1–26.3)	8.3 (3.0–10.1)	10.8 (6.6–20.9)	4.0* (2.7–8.8)
Band neutrophil ($10^3/\mu L$) (n = 20)	0.0–0.5	0.5 (0.0–0.4)	0.2 (0.0–2.9)	0.0 (0.0–0.3)	0.0 (0.0–2.1)	0.1 (0.0–0.4)
Lymphocyte ($10^3/\mu L$) (n = 19)	1.7–4.7	1.9 (1.3–2.7)	2.4 (1.8–3.6)	1.6 (0.9–2.2)	1.7 (0.8–2.8)	1.8 (1.6–2.4)
Fibrinogen (mg/dl) (n = 21)		364 (222–729)	461 (343–1052)	326 (186–417)	354 (182–862)	388 (233–741)

[a] Source for neonatal (<30 days of age) values: Fowler and Zinkl.[13]
[b] No values were outside normal range.
* Significantly different Gram-positive ($P \leq 0.05$).

Treatments

Initial antimicrobial therapy was appropriate in all patients treated on the basis of the antibiograms of their individual identified isolates. Ceftiofur sodium[c] was the initial antimicrobial chosen in 17 crias. Other antimicrobials intermittently used (at admission or during hospitalization) included penicillin, ampicillin, gentamicin, amikacin, and metronidazole. Balanced isotonic crystalloid fluids were administered IV to 15 crias; 16 received IV plasma transfusions. IV dextrose supplementation was provided to 16 patients, 6 of which subsequently also received parenteral nutrition. Average length of hospital stay was 5.0 (2.5–9.75) days. There were no differences in duration of hospitalization based on outcome or categorization of infection based on gram-staining characteristics of the isolated bacteria. In no instance was there evidence in the medical record that a patient was euthanized for other than humane reasons (ie, no cria was euthanized for economic considerations alone).

Discussion

This retrospective study presents findings in a relatively small number of neonatal NW camelids with culture-positive sepsis presenting to a referral hospital. In our hospital, it is standard procedure for admission blood cultures to be obtained from all presenting neonates, regardless of species, making it unlikely that many cases with bacteremia at admission were missed. Because this study was limited to crias with positive cultures, crias with bacterial infections that were not identified during the course of hospitalization have not been included, nor have crias been included in which the clinician had a high index of suspicion for sepsis that was not documented by positive culture.

A generally accepted working clinical definition of sepsis is systemic inflammatory response syndrome (SIRS) associated with documented or suspected infection, with infection being bacterial, viral, fungal, or rickettsial.[15,16] Most SIRS definitions revolve around the clinical signs of fever or hypothermia, leukocytosis or leukopenia, tachycardia, and tachypnea; infection is not a requirement.

A recent international sepsis forum consensus conference provided definitions for bloodstream infections in the intensive care unit, and a similar consensus conference provided definitions of pediatric SIRS, sepsis, and organ dysfunction that are age-specific.[17,18] Considerable overlap exists in other species of the constellation of clinical signs associated with sepsis and SIRS, but to our knowledge, no specific consensus veterinary definition of either syndrome has appeared in peer-reviewed veterinary literature. No large studies have reported on or defined sepsis or SIRS in NW camelid crias. Lacking a specific definition of SIRS or sepsis and for the purposes of our study, we diagnosed sepsis in culture-positive patients that exhibited signs of systemic manifestation of organ dysfunction in an attempt to eliminate crias exhibiting SIRS but without infection.

In this study, it appeared that more females than males presented with sepsis. Because of the small numbers involved and our inability to eliminate confounding effects, such as the willingness of owners to hospitalize males as frequently as females, we are unable to draw conclusions regarding sex predisposition. Nonsurviving crias were presented at a more-advanced age, but this finding was not significant. Good outcome (ie, survival to discharge) for other veterinary species with neonatal sepsis, most notably foals, is associated with early presentation and treatment, and earlier referral may improve outcome for crias with sepsis.[3,19] The presenting complaints in the crias in this study were not dissimilar to those of other veterinary neonates, and sepsis should be suspected in crias with signs of weakness or failure to suck well. Prematurity or suspected prematurity was reported in 8 of 21 (38%) crias. Crias with the previously described clinical signs and a history of premature delivery may be at greater risk for sepsis. Problems such as maternal disease or dystocia were reported in approximately 20% of crias, and because these problems are known to be associated with neonatal disease in other species, special attention should be paid to crias with maternal or parturition

Table 5. Clinical biochemistry and blood gas findings in culture-positive septic neonatal crias at admission. Data are presented as median (25th–75th percentile). Gram-positive/-negative indicates major bacteriologic isolate.

Parameter	Reference Range[a]	All Crias	Nonsurvivors	Survivors	Gram-positive	Gram- negative
Glucose (mg/dl) (n = 19)	94–170	100 (25–165)	98 (23–137)	100 (30–172)	135 (24–179)	71 (30–147)
Creatinine (mg/dl) (n = 21)	1.1–2.9	2.3 (1.6–3.7)	2.0 (1.4–4.0)	2.4 (1.7–3.7)	2.1 (1.6–4.4)	2.8 (1.6–3.7)
Sodium (mmol/L) (n = 20)	148–155	153 (148–155)	151 (148–155)	154 (148–155)	151 (148–155)	154 (149–155)
Chloride (mmol/L) (n = 20)	101–116	113 (110–118)	112 (101–119)	115 (111–118)	113 (111–119)	114 (109–118)
Potassium (mmol/L) (n = 20)	4.6–5.9	3.84[b] (3.49–4.89)	4.93* (3.74–6.10)	3.74[b] (3.00–4.27)	3.81[b] (3.59–4.85)	3.87[b] (2.94–5.14)
Calcium (mg/dL) (n = 15)	9.4–10.6	10.3 (9.7–11.0)	10.4 (9.3–11.3)	10.3 (9.9–10.9)	9.8 (9.5–10.8)	10.4 (10.0–11.2)
pH (n = 15)	NA	7.41 (7.37–7.44)	7.41 (7.30–7.43)	7.42 (7.38–7.44)	7.43 (7.40–7.47)	7.41 (7.34–7.44)
PCO_2 (n = 9)	NA	40 (31–44)	36 (23–48)	42 (31–44)	38 NA	40 (29–43)
Lactate (mmol/L) (n = 14)	NA	2.05 (1.35–2.90)	2.39 (1.40–2.90)	1.90 (1.20–2.40)	2.0 (1.6–2.5)	2.4 (1.2–3.0)

NA, not available.

[a] Source for neonatal (<30 days of age) values: Fowler and Zinkl.[13]

[b] Outside normal range for llama crias.

* Significantly different from survivors (P≤ 0.05).

problems in the history.[20–22] Treatments administered before presentation were not unusual compared with those administered to other species and were directed at either suspected or confirmed FPT or suspected infection or both. Failure of FPT, suspected or documented, was common in this group of crias and, as in other species, likely had a role in acquisition of infection.[9–11] Alternately, because these crias had established infections before IgG concentrations were measured, their low IgG concentrations may be in part secondary to catabolism of sepsis. Of note is the lack of difference in total protein (TP) between those with and without FPT. TP previously had been reported to be a reliable indicator of passive transfer status in healthy crias between 1 and 3 days of age, but our observations suggest that TP should not be used as an indicator of IgG concentration in sick crias.[23] We suggest that factors such as production of acute inflammatory proteins, hydration status, circulating volume status, and catabolism all may play a role in making TP an unreliable indicator of IgG concentration in sick crias.

Median rectal temperature (T) was unremarkable, and although some individuals were mildly to moderately hypothermic (T < 100.0°F) at presentation (7/21), fever was not a feature of septic crias in this study. Tachypnea and tachycardia were present in many septic crias at admission (Table 1). Tachypnea can be present as a response to central, respiratory, thermoregulatory, or acid-base abnormalities. Tachypnea also is a component of most SIRS definitions.[15,16] Fever and acid-base disorders were not present in most of the crias in this study (Tables 1, 3), and SIRS, central disorders, or respiratory compromise must all be considered in tachypneic crias.

Tachycardia can be present as a response to fever, excitement, poor oxygen delivery to tissues, poor cardiac output, hypovolemia, hypotension, or other factors and is also a component of SIRS definitions. Fever was not a finding in these crias, and although some crias presented standing, excitement was not a finding in these neonates at the time of presentation. We cannot assess what effect stress associated with handling may have had on heart rate in these crias. Lactate concentration has been used as an indicator of decreased perfusion and poor tissue oxygen delivery or decreased oxygen utilization in critically ill humans and animals.[24–27] Posthoc regression of lactate on heart rate was not significant ($P = 0.42$, $r^2 = 5.8\%$); as opposed to critically ill foals, most of these septic crias did not have high lactate concentrations (Table 3), suggesting that lactate homeostasis may be different in NW camelids. Presentation PaO_2 values were not reported because many of these crias had been placed on intranasal oxygen insufflation at the time blood gas analysis was performed and had adequate arterial oxygen tensions. Thus, substantial hypoxemia was felt to be an unlikely contributor to lactate concentration. Anemia was identified in only 1 cria. Hypovolemia, hypotension, or both, resulting in a need for increased heart rate to maintain cardiac output, was a likely contributor to tachycardia in these patients. Sepsis is known to result in hypotension and can proceed to septic shock.[15,16] Neonates, although generally protected from intravascular volume challenges by their large interstitial fluid reserve, can present with substantial hypovolemia once their redistributive capacity is exceeded, especially in the face of poor vascular control, and may require aggressive fluid resuscitation.[28] Indirect blood pressure measurements were not always performed in these crias, and no normal range of either direct or indirect systemic blood pressure measurements has been described for crias.

There was no association between ability to stand or suck at presentation and outcome. This is different from what has been reported in other species, in which

Table 6. Bacteria isolated from crias either at presentation or during subsequent testing. There were 2 cases of mixed infections, neither of which survived, and 1 case, a nonsurvivor, where 2 gram-positive organisms were isolated at 2 different samples, admission and after admission.

Organism	Number of Isolates	% Total Isolates	% Survived
Gram-positive	11	46	64
Enterococcus spp.	4	17	100
Listeria monocytogenes	3	13	33
Coagulase-negative *Staphylococcus* spp.	2	8	100
Bacillus spp.	1	0.5	0
Corynebacterium spp.	1	0.5	0
Gram-negative	13	54	64
Escherichia coli	4	17	50
Klebsiella spp.	2	8	100
Citrobactor amalonaticus	2	8	100
Citrobactor freundii	1	0.5	0
Enterobacter spp.	1	0.5	0
CDC Ve 2	1	0.5	0
CDC enteric 76	1	0.5	100
Aerobic rod (probable *Acinetobacter* spp.)	1	0.5	100

CDC, Centers for Disease Control and Prevention.

recumbency or loss of suck is associated with disease severity and poor outcome, and may reflect another way in which crias with sepsis differ.[29] In survival studies of neonatal foals with sepsis, models that encompass a range of serum biochemical and hematology abnormalities have been developed to predict outcome.[29–32] In the study reported here, no such distinguishing differences, excepting plasma potassium concentration, were identified. These findings may preclude development of models in crias similar to those developed for equine neonates, although study of larger numbers of sick crias is required to confirm this impression.

Gastrointestinal and central nervous system dysfunction were associated with outcome in that more crias without these systemic manifestations survived. Because of the small number of animals presented in this study and its retrospective nature, it is difficult to draw firm conclusions, but crias that present or develop clinical signs of dysfunction in these organ systems seem to have a poorer prognosis.

Although the number of patients was small, gram-negative and gram-positive organisms were isolated in approximately the same frequency and had identical survival percentages. The only previous case series of culture-positive bacterial sepsis in crias described primarily gram-negative infections in 6 crias.[11] It appears that gram-negative infections are more commonly associated with leukopenia and neutropenia, whereas infection with *L monocytogenes* may produce leukocytosis and neutrophilia. *E coli* infection, as in other species, appears to carry a poorer prognosis, as does infection with *L monocytogenes*.[11,33–36] Conversely, all crias with *Enterococcus* spp. infections survived. On the basis of the antibiograms of individual bacterial isolates, the initial antimicrobial choices were appropriate for each patient. To our knowledge, there are few reports of the pharmacokinetics of commonly used antimicrobial agents in crias, and dosages are most commonly adapted from those described for other large animal neonates.

In this retrospective study of blood culture–positive neonatal crias, there was an overall survival to discharge of 67%, comparable to reported survival in septic foals.[5,33,37] FPT of immunity may play a role in the development of neonatal sepsis. Cria owners and referring veterinarians were aware of this association, as evidenced by the frequency of additional colostrum feedings and plasma transfusions administered before admission. Affected crias may not have localizing signs at presentation and are not usually febrile, although hypothermia is relatively common. Total protein concentration may not be a reliable indicator of IgG plasma concentrations in sick or septic crias. Crias with culture-positive sepsis did not have substantial clinical biochemistry or blood gas abnormalities as seen in other species of similar age with similar problems, potentially complicating diagnosis. As the NW camelid population continues to increase in North America, referral hospitals can expect to see more of these patients. Familiarity with the clinical presentation and common pathogens isolated should improve early recognition, treatment, and ultimately outcome of crias with sepsis.

Footnotes

[a] BBL Septi-Check, Becton-Dickinson Microbiology Systems, Sparks, MD

[b] Minitab, version 12.1, State College, PA

[c] Ceftiofur sodium, Naxcel, Pharmacia & Upjohn Company, Kalamazoo, MI

References

1. McGuire TC, Crawford TB, Hallowell AL, et al. Failure of colostral immunoglobulin transfer as an explanation for most infections and deaths of neonatal foals. J Am Vet Med Assoc 1977;170:1302–1304.

2. McGuire TC, Pfeiffer NE, Weikel JM, et al. Failure of colostral immunoglobulin transfer in calves dying from infectious disease. J Am Vet Med Assoc 1976;169:713–718.

3. Paradis MR. Update on neonatal septicemia. Vet Clin North Am Equine Pract 1994;10:109–135.

4. Stoneham SJ, Digby NJ, Ricketts SW. Failure of passive transfer of colostral immunity in the foal: Incidence, and the effect of stud management and plasma transfusions. Vet Rec 1991;128: 416–419.

5. Aldridge BM, Garry FB, Adams R. Neonatal septicemia in calves: 25 cases (1985–1990). J Am Vet Med Assoc 1993;203: 1324–1329.

6. Tsur I, Harmelin A, Dvir I, et al. Meningoencephalitis and brain abscessation due to *Escherichia coli* in a 2 week old alpaca cria. Aust Vet J 1996;74:437–438.

7. Frank N, Couetil LL, Clark KA. *Listeria monocytogenes* and *Escherichia coli* septicemia and meningoencephalitis in a 7-day-old llama. Can Vet J 1998;39:100–102.

8. Anderson NV, Anderson DE, Leipold HW, et al. Septicemic salmonellosis in two llamas. J Am Vet Med Assoc 1995;206:75–76.

9. Garmendia AE, Palmer GH, Di Martini JC, et al. Failure of passive immunoglobulin transfer: A major determinant of mortality in newborn alpacas (*Lama pacos*). Am J Vet Res 1987;48: 1472–1476.

10. Wernery U. Camelid immunoglobulins and their importance for the new-born: A review. J Vet Med B Infect Dis Vet Public Health 2001;48:561–568.

11. Adams R, Garry FB. Gram-negative bacterial infection in neonatal New World camelids: Six cases (1985–1991). J Am Vet Med Assoc 1992;201:1419–1424.

12. Fowler ME. Medicine and Surgery of South American Camelids, 2nd ed. Ames, Iowa: Iowa State University Press; 1998.

13. Fowler ME, Zinkl JG. Reference values for hematologic and serum biochemical values in llama (*Lama glama*). Am J Vet Res 1989;50:2049–2053.

14. Eastman Kodak Company. Veterinary Reference Guide for Kodak EKTACHEM Products. Available from the Clinical Diagnostic Division, Eastman Kodak Company, Rochester, NY 14650.

15. Bone RC, Sprung CL, Sibbald WJ. Definitions for sepsis and organ failure. Crit Care Med 1992;20:724–726.

16. Opal M. Severe sepsis and septic shock: Defining the clinical problem. Scand J Infect Dis 2003;35:529–534.

17. Calandra T, Cohen J, and The International Sepsis Forum Definition of Infection in the ICU Consensus Conference, The international sepsis forum consensus conference on definitions of infection in the intensive care unit. Crit Care Med 2005;33: 1538–1548.

18. Goldstein B, Giroir B, Randolf A, and International Consensus Conference on Pediatric Sepsis, International pediatric sepsis consensus conference: Definitions for sepsis and organ dysfunction in pediatrics. Pediatr Crit Care Med 2005;6:2–8.

19. Roy MF. Sepsis in adults and foals. Vet Clin North Am Equine Pract 2004;20:41–61.

20. Haas SD, Bristol F, Card CE. Risk factors associated with the incidence of foal mortality in an extensively managed mare herd. Can Vet J 1996;37:91–95.

21. Cohen ND. Causes of and farm management factors associated with disease and death in foals. J Am Vet Med Assoc 1994;204:1644–1651.

22. Christley RM, Morgan KL, Parkin TD, et al. Factors related to the risk of neonatal mortality, birth-weight and serum immunoglobulin concentration in lambs in the UK. Prev Vet Med 2003;57:209–226.

23. Weaver DM, Tyler JW, Marion RS, et al. Evaluation of assays for determination of passive transfer status in neonatal llamas and alpacas. J Am Vet Med Assoc 2000;216:559–563.

24. Luft FC. Lactic acidosis update for critical care clinicians. J Am Soc Nephrol 2001;17:S15–19.

25. Nguyen HB, Rivers EP, Knoblich BP, et al. Early lactate clearance is associated with improved outcome in severe sepsis and septic shock. Crit Care Med 2004;32:1637–1642.

26. Corley KT, Donaldson LL, Furr MO. Arterial lactate concentration, hospital survival, sepsis and SIRS in critically ill neonatal foals. Equine Vet J 2005;37:53–59.

27. Wotman K, Palmer JE, Boston RC, et al. Lactate concentration in foals presenting to a neonatal intensive care unit: Association with outcome. J Vet Intern Med 2005;19:409.

28. Palmer JE. Fluid therapy in the neonate: Not your mother's fluid space. Vet Clin North Am Equine Pract 2004;20:63–75.

29. Rohrback BW, Buchanan BR, Drake JM, et al. Use of a multivariable model to estimate the probability of discharge in hospitalized foals that are 7 days of age or less. J Am Vet Med Assoc 2006;228:1748–1756.

30. Furr M, Tinker MK, Edens L. Prognosis for neonatal foals in an intensive care unit. J Vet Intern Med 1997;11:183–188.

31. Hoffman AM, Staempfli HR, Willan A. Prognostic variables for survival of neonatal foals under intensive care. J Vet Intern Med 1992;6:89–95.

32. Gayle DM, Cohen ND, Chaffin KM. Factors associated with survival in septicemic foals: 65 cases (1988–1995). J Vet Intern Med 1998;12:140–146.

33. Wilkins PA, Marsh PS, Acland H, et al. *Listeria monocytogenes* septicemia in a Thoroughbred foal. J Vet Diagn Invest 2000;12:173–176.

34. Wallace SS, Hathcock TL. *Listeria monocytogenes* septicemia in a foal. J Am Vet Med Assoc 1995;207:1325–1326.

35. Jose-Cunilleras, Hinchcliff KW. *Listeria monocytogenes* septicaemia in foals. Equine Vet J 2001;33:519–522.

36. Posfay-Barbe KM, Wald ER. Listeriosis. Pediatr Rev 2004;25:151–159.

37. Raisis AL, Hodgdson JL, Hodgson DL. Equine neonatal septicaemia: 24 cases. Aust Vet J 1996;73:137–140.