Assessment of cerebrospinal fluid analysis and short-term survival outcomes in South American camelids: A retrospective study of 54 cases (2005-2021)

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Abstract

Background: Cerebrospinal fluid (CSF) is commonly analyzed in South American camelids with suspected neurologic disease because of ease of collection and characteristic findings associated with certain diseases.

Objectives: To assess CSF findings associated with short-term survival or non-survival in South American camelids in which neurologic disease was a differential diagnosis based on history and physical examination.

Animals: Twenty-one llamas and 33 alpacas that underwent CSF analysis at the University of Missouri Veterinary Health Center.

Methods: Retrospective study. Medical records of camelids that underwent CSF analysis between January 2005 and September 2021 were studied. Short-term survival was defined as survival to discharge from the Veterinary Health Center. A Fisher’s exact test was used to compare species, CSF results, and survival.

Results: Odds of survival were 3.9 times higher in camelids with a total nucleated cell count (TNCC) <3 cells/μL (P = .04). No significant association was found between survival and total protein concentration (TPC; P = .15) or percentage of eosinophils (P = 1.0). No significant correlation was found between species and increased TNCC (P = .63), TPC (P = .55), or percentage of eosinophils (P = .30). Among camelids diagnosed with *Paraschostralynx tenuis* infestation, odds of survival were 4.95 times higher in alpacas (P = .05).

Conclusions: Cerebrospinal fluid TNCC ≥3 cells/μL is associated with decreased odds of short-term survival in South American camelids.

KEYWORDS
alpaca, Camelidae, cerebrospinal nematodiasis, eosinophilia, llama, meningeal worm, neurologic disease, neutrophilia, New World camelids, *Paraschostralynx tenuis*, spinal cord

Abbreviations: CSF, cerebrospinal fluid; RBC, red blood cell (erythrocyte); TNCC, total nucleated cell count; TPC, total protein concentration.

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Analysis of cerebrospinal fluid (CSF) is commonly employed in veterinary medicine and has been used in many species, including South American camels (llamas and alpacas). In these species, CSF analysis has been shown to be effective in presumptive ante-mortem diagnosis of many conditions. For example, it has been reported that the presence of >17% eosinophils in CSF had a sensitivity of 85% and a specificity of 92% for the diagnosis of Parelaphostrongylus tenuis (P. tenuis; meningeal worm) cerebrospinal nematodiasis. Additionally, several common neurologic disease processes in camels produce characteristic changes in CSF, such as neutrophilic pleocytosis with bacterial meningitis and mononuclear pleocytosis with listeriosis.

In most cases, CSF can be obtained easily from the lumbosacral space without sedation, using a local anesthetic. Previous reports on CSF collection in ruminants reported no adverse sequelae under on-farm conditions, and the use of local anesthesia avoids the risks associated with general anesthesia. Because CSF collection is relatively simple to perform and is of diagnostic value in identifying several life-threatening conditions, it is a valuable tool in determining the etiology of neurologic disease in camels and initiating appropriate treatment. However, published reports on the use of CSF analysis to diagnose disease and provide a prognosis in camels are limited compared to other species. Based on research in other species, it is likely that detection of characteristic abnormalities on CSF analysis in llamas and alpacas is a sensitive and specific method of ante-mortem diagnosis of neurologic diseases. The severity of changes noted on CSF analysis could be used as a prognostic indicator to assess the severity of disease and the odds of survival or response to treatment in camels with neurologic disease. Because many neurologic diseases in these species carry a poor prognosis and may progress rapidly, early and accurate ante-mortem diagnosis and prognosis assessment play important roles in client decision-making and treatment planning and potentially could impact treatment efficacy.

Although research in llamas and alpacas is limited, previous studies have reported normal CSF results in these species to include a total nucleated cell count (TNCC) of <3 cells/μL and a total protein concentration (TPC) of <45 mg/dL. Eosinophils are not found in the CSF of healthy llamas and alpacas, and their presence in a CSF sample without blood contamination is suggestive of P. tenuis infestation. Based on these previous reports, we hypothesized that camels with a CSF TNCC of <3 cells/μL, a CSF TPC of <50 mg/dL, or <10% eosinophils noted on CSF or some combination of these findings would have higher odds of short-term survival than camels with CSF results higher than these thresholds. Our objective was to determine CSF findings associated with survival or non-survival in South American camels presented to a veterinary teaching hospital and that had neurologic disease included as a differential diagnosis based on history and physical examination findings.

The electronic medical records from the University of Missouri Veterinary Health Center were retrospectively reviewed. Data was included from January 1, 2005 to September 30, 2021. Animals were eligible for inclusion if they were llamas or alpacas and had CSF collection and analysis performed during hospitalization.

All CSF samples were aseptically collected from the lumbosacral intervertebral space and placed in an ethylenediaminetetraacetic acid vacutainer tube for cytology and clinicopathologic analysis. Cerebrospinal fluid analysis was performed by a board-certified clinical pathologist at the University of Missouri Veterinary Medical Diagnostic Laboratory. The CSF TNCC, TPC, and percentage of eosinophils were noted for each camelid, as well as whether or not blood contamination was reported based on the presence of red blood cells in the sample.

Cerebrospinal fluid samples that reported blood contamination were further assessed for the concentration of erythrocytes to rule out blood contamination influencing CSF analysis. If erythrocytes were present in numbers >13 200 cells/μL in the CSF, it was noted that the TNCC and TPC may have been falsely increased. All samples were included in the final results regardless of contamination because of the common occurrence of blood contamination in CSF collection and the small sample size.

Camelids were divided into 2 groups based on short-term survival status. Animals were identified as survivors if they were successfully discharged from the Veterinary Health Center. Animals were identified as non-survivors if they died or were euthanized during hospitalization.

Absolute numbers and proportions were calculated for all descriptive data including species, survival status, TNCC, TPC, and percentage of eosinophils. Statistical analysis was performed using Fisher’s exact tests using commercial software (Stata/IC 13.1; StataCorp LLC, College Station, Texas) to compare whether or not TNCC, TPC, and percentage of eosinophils exceeded the reference intervals in both the survivor group and the non-survivor group, as well as in both species. Data were analyzed using commercial software (Sigma Plot 14.0; Systat Software, San Rafael, California) to determine P values. Results were considered significant when P was ≤ .05.
separately because they represented separate visits. All other camelids had 1 sample collected. Demographic data of included camelids are summarized in Table 1. All included camelids had CSF collection performed to rule out a differential diagnosis of neurologic disease. Of the 54 included camelids, 50% (27/54) were recumbent, 46.3% (25/54) were ataxic, 1.85% (1/54) had a head tilt, and 1.85% (1/54) had head tremors.

Twenty-three (42.6%) included camelids either died during hospitalization (3) or were euthanized (20), whereas 31 (57.4%) survived to discharge. Of the surviving camelids, 29% (9/31) were llamas and 71% (22/31) were alpacas. Of the non-surviving camelids, 52.2% (12/23) were llamas and 47.8% (11/23) were alpacas. No significant correlation was found between species and odds of survival, but the odds of short-term survival were 2.66 times higher in alpacas than in llamas ($P = .09$). Surviving camelids had a shorter median duration of hospitalization of 2.5 days (range, 1-16 days) compared to camelids that did not survive to discharge (median duration of hospitalization, 4 days; range, 1-11 days). Median duration of hospitalization for all animals was 4 days (range, 1-16 days).

Overall, 53.7% (29/54) of the camelids included in the study had been presumptively diagnosed with $P. tenuis$ infestation, 44.8% (13/29) of which were llamas and 55.2% (16/29) of which were alpacas. Nine of the 54 included camelids (16.7%) were presumptively or definitively diagnosed with neurologic diseases other than $P. tenuis$ infestation, whereas 29.6% (16/54) were presumptively or definitively diagnosed with non-neurologic disease. Diagnoses of included camelids are summarized in Table 2.

Cerebrospinal fluid analysis findings for included camelids are summarized in Table 3. Regardless of species, non-surviving camelids had higher median values for TNCC, TPC, and percentage of eosinophils compared to surviving camelids, with the exception of percentage of eosinophils in llamas. No significant correlation was found between species and odds of a TNCC $\geq 3$ cells/μL ($P = .63$), a TPC $\geq 50$ mg/dL ($P = .55$), or a percentage of eosinophils $\geq 10$% ($P = .30$).

### Table 1: Demographics of included camelids (n = 54)

| Species | Included | Age          | Females | Intact males | Geldings |
|---------|----------|--------------|---------|--------------|----------|
| Llama   | 38.9% (21) | 7.5 y [0.8-16 y] | 57.1% (12) | 19% (4) | 23.8% (5) |
| Alpaca  | 61.1% (33) | 5.0 y (<0.1-14.0 y) | 54.5% (18) | 33.3% (11) | 12.1% (4) |

Note: Data are presented as median [range] or % (n).

### Abbreviation: y, years of age.

### Table 2: Diagnoses (presumptive or definitive) of included camelids (n = 54)

| System          | Diagnosis                                  | No. camelids | Survivors | Non-survivors |
|-----------------|--------------------------------------------|--------------|-----------|---------------|
| Neurologic      | Paralephostrongylus tenuis infestation     | 29           | 17        | 12            |
|                 | Meningitis                                 | 2            | 0         | 2             |
|                 | Arachnoid cyst                             | 1            | 0         | 1             |
|                 | Blindness (unknown cause)                  | 1            | 1         | 0             |
|                 | Cervical vertebral malformation            | 1            | 1         | 0             |
|                 | Listeriosis                                | 1            | 1         | 0             |
|                 | Spinal neoplasia                           | 1            | 0         | 1             |
|                 | Traumatic spinal hemorrhage and necrosis   | 1            | 0         | 1             |
|                 | Unknown neurologic disease                 | 1            | 1         | 0             |
| Systemic        | Apparently healthy                         | 2            | 2         | 0             |
|                 | Heat stroke                                | 1            | 1         | 0             |
|                 | Hypophosphatemia                           | 1            | 1         | 0             |
| Gastrointestinal| Gastrointestinal parasitism                | 2            | 1         | 1             |
|                 | Gastric ulcer                              | 1            | 0         | 1             |
|                 | Rectal prolapse                            | 1            | 1         | 0             |
| Musculoskeletal | Septic arthritis                           | 1            | 1         | 0             |
|                 | Degenerative joint disease                 | 1            | 1         | 0             |
| Respiratory     | Pneumonia                                  | 2            | 0         | 2             |
| Renal           | Hyperosmolar syndrome                      | 1            | 1         | 0             |
|                 | Renal failure                              | 1            | 0         | 1             |
| Cardiovascular  | Saddle thrombus                            | 1            | 0         | 1             |
| Reproductive    | Prostatitis                                | 1            | 1         | 0             |
Blood contamination was reported in 28 camelids, 32.1% (9/28) of which were llamas and 67.9% (19/28) of which were alpacas. Demographics of camelids in which blood contamination was reported on CSF analysis are summarized in Table 4. No significant correlation was found between species and odds of blood contamination being reported, either among all camelids in which blood contamination was reported (\(P = .29\)), in those with an erythrocyte concentration > 13,200 cells/\(\mu L\) (\(P = .39\)), or in those with an erythrocyte concentration ≤ 13,200 cells/\(\mu L\) (\(P = .82\)). No significant correlation was found between camelids having an erythrocyte concentration > 13,200 cells/\(\mu L\) and species (\(P = .55\)) or survival status (\(P = .14\)). Among camelids with an erythrocyte concentration > 13,200 cells/\(\mu L\) on CSF, the odds of survival were 32.1 times higher in alpacas than in llamas (\(P = .03\)), but no significant correlations were found between species and survival status among camelids with an erythrocyte concentration > 13,200 cells/\(\mu L\) on CSF (\(P = .21\)) or among all camelids in which blood contamination was reported (\(P = .34\)).

Ten of the 28 camelids in which blood contamination was reported (35.7%) had necropsy results available. Of these 10 camelids, 20% (2/10) had evidence of hemorrhage in the spinal cord; 1 alpaca had hemosiderin present in macrophages in the spinal cord on histology, whereas another alpaca showed macroscopic hemorrhage in the spinal cord. Therefore, the erythrocytes present in the CSF of these 2 animals were deemed most likely to be the consequence of central nervous system hemorrhage rather than contamination.

A significant correlation (\(P = .04\)) was found between short-term survival and TNCC < 3 cells/\(\mu L\) for all included camelids. The odds of short-term survival were 3.9 times higher in camelids with a TNCC < 3 cells/\(\mu L\). No significant association was found between short-term survival and TPC < 50 mg/dL (\(P = .15\)) or percentage of eosinophils < 10% (\(P = 1.0\)). Among the included llamas, the odds of short-term survival were 6.25 times higher in llamas with a TNCC < 3 cells/\(\mu L\) and 7 times higher in llamas with a percentage of eosinophils < 10%, but these findings were not significant (\(P = .07\) and .05, respectively). No significant association was found between short-term survival and TPC < 50 mg/dL in llamas (\(P = .16\)). Among the 33 included alpacas, no significant association was found between short-term survival and TNCC < 3 cells/\(\mu L\) (\(P = 1.0\)), TPC < 50 mg/dL (\(P = .29\)), or percentage of eosinophils < 10% (\(P = .20\)).

### Table 3: Summary of cerebrospinal fluid findings in included camelids

| Group                  | No. camelids | TNCC (cells/\(\mu L\)) | TNCC ≥ 3 cells/\(\mu L\) | TPC (mg/dL) | TPC ≥ 50 mg/dL | Eosinophils (%) | Eosinophils ≥ 10% |
|------------------------|--------------|-------------------------|---------------------------|-------------|----------------|-----------------|-------------------|
| All                    | 54           | 8 [0-730]               | 70.4% (38)                | 68.5 [24-917] | 66.7% (36)     | 8.25 [0-96]     | 38.9% (21)       |
| All llamas             | 21           | 8 [0-650]               | 66.7% (14)                | 67 [25-828]  | 61.9% (13)     | 38 [0-94]       | 47.6% (10)       |
| All alpacas            | 33           | 10.5 [0-730]            | 72.7% (24)                | 69 [24-917]  | 69.7% (23)     | 0 [0-96]        | 33.3% (11)       |
| All surviving          | 31           | 5 [0-650]               | 64.5% (20)                | 58 [24-247]  | 58.1% (18)     | 0.5 [0-96]      | 35.5% (11)       |
| Surviving llamas       | 9            | 2 [0-650]               | 44.4% (4)                 | 49 [25-140]  | 44.4% (4)      | 42.5 [0-94]     | 22.2% (2)        |
| Surviving alpacas      | 22           | 5.5 [0-535]             | 72.7% (16)                | 59 [24-247]  | 63.6% (14)     | 0 [0-96]        | 40.9% (9)        |
| All non-surviving      | 23           | 34 [0-730]              | 78.3% (18)                | 113 [24-917] | 78.3% (18)     | 13 [0-95]       | 43.5% (10)       |
| Non-surviving llama    | 12           | 8.5 [1-290]             | 83.3% (10)                | 96 [28-828]  | 75% (9)        | 38 [0-90]       | 66.7% (8)        |
| Non-surviving alpaca   | 11           | 80 [0-730]              | 72.7% (8)                 | 118 [24-917] | 81.8% (9)      | 1 [0-95]        | 18.2% (2)        |

Note: Data are presented as median [range] or % (n).
Abbreviations: TNCC, total nucleated cell count; TPC, total protein concentration.

### Table 4: Demographics of included camelids in which blood contamination was reported on CSF analysis

| Group                  | No. camelids | RBCs ≤ 13,200 cells/\(\mu L\) | RBCs > 13,200 cells/\(\mu L\) |
|------------------------|--------------|--------------------------------|-------------------------------|
| All                    | 28           | 67.9% (19)                      | 28.6% (8)                     |
| All llamas             | 9            | 77.8% (7)                       | 22.2% (2)                     |
| All alpacas            | 19           | 63.2% (12)                      | 31.6% (6)                     |
| All surviving          | 19           | 78.9% (15)                      | 21.1% (4)                     |
| Surviving llamas       | 5            | 60.0% (3)                       | 40.0% (2)                     |
| Surviving alpacas      | 14           | 85.7% (12)                      | 14.3% (2)                     |
| All non-surviving      | 9            | 44.4% (4)                       | 44.4% (4)                     |
| Non-surviving llama    | 4            | 100% (4)                        | 0% (0)                        |
| Non-surviving alpaca   | 5            | 0% (0)                          | 80.0% (4)                     |

Note: Data on erythrocyte concentration was not available for one non-surviving alpaca because of clotting of the sample interfering with measurements. Data are presented as % (n).
Abbreviations: CSF, cerebrospinal fluid; RBC, red blood cell (erythrocyte).
Demographics of the included camelids with a presumptive or definitive diagnosis of *Paralephostrongylus tenuis* infestation

| Group                  | Number of animals diagnosed with *P. tenuis* infestation | Number of animals with other diagnoses |
|------------------------|----------------------------------------------------------|---------------------------------------|
| All (n = 54)           | 29 (53.7%)                                               | 25 (46.3%)                            |
| All llamas (n = 21)   | 13 (61.9%)                                               | 8 (38.1%)                             |
| All alpacas (n = 33)   | 16 (48.5%)                                               | 17 (51.5%)                            |
| All surviving (n = 31) | 15 (48.4%)                                               | 16 (51.6%)                            |
| Surviving llamas (n = 9) | 4 (44.4%)                          | 5 (55.6%)                             |
| Surviving alpacas (n = 22) | 13 (59.1%)             | 9 (40.9%)                             |
| All non-surviving (n = 23) | 14 (60.9%)            | 9 (39.1%)                             |
| Non-surviving llamas (n = 12) | 9 (75.0%)                | 3 (25.0%)                             |
| Non-surviving alpacas (n = 11) | 3 (27.3%)            | 8 (72.7%)                             |

Demographics of the 29 included camelids presumptively or definitively diagnosed with *P. tenuis* infestation are summarized in Table 5. No significant association was found between species and diagnosis of *P. tenuis* infestation (*P* = .37). No significant correlation was found between diagnosis with *P. tenuis* infestation and survival status, either among all included camelids (*P* = .36) or in llamas (*P* = .16) or alpacas (*P* = .81). The odds of survival were 4.95 times higher in alpacas diagnosed with *P. tenuis* infestation than in llamas with the same diagnosis (*P* = .05).

4 | DISCUSSION

Our results suggest that a TNCC ≥3 cells/μL on CSF analysis is significantly associated with decreased odds of short-term survival in camelids. This finding is consistent with previous literature, which established that the reference range for TNCC in camelid CSF is <3 cells/μL. Total nucleated cell counts in healthy animals tend to be low regardless of species. A previous study on cattle determined that a TNCC higher than the threshold of 4.5 cells/μL yielded a specificity of 100% for diagnosing downer dairy cows with spinal lesions, whereas in horses, normal CSF TNCC ranges were reported to be from 0 to 6 cells/μL. Thus, increases in TNCC are associated with disease of the central nervous system and can be extrapolated as a negative prognostic indicator for survival in affected animals. To our knowledge, no studies have compared TNCC and survival status in camelids with neurologic disease, but a retrospective study on downer cows found that cows with TNCC above the reference interval were significantly less likely to survive than cows with TNCC within the reference interval. No significant correlation was found in that study between survival and increases in TPC or percentage of eosinophils on CSF. These findings support the hypothesis that CSF TNCC is of value in prognostic assessment of neurologic disease in camelids.

Camelids that died or were euthanized during the study had higher median and maximum results for TNCC, TPC, and percentage of eosinophils, suggesting that increases in these variables may be associated with poorer prognosis. However, these results were not statistically significant. A major limitation of our study was small sample size, which limited the statistical analysis. Additionally, the retrospective nature of our study limited analysis of other possible contributing factors that could impact prognosis and survival, including duration of recumbency, and presence and severity of comorbidities such as dehydration, electrolyte abnormalities, anemia, and secondary infections. Further research using a larger population of camelids from multiple institutions would likely result in more definitive conclusions. A larger sample population also would allow for assessment of outcomes based on other factors that may impact survival odds in camelids, such as age or diagnoses other than *P. tenuis* infestation. These factors could not be evaluated because of the small sample size in our study.

No significant associations were found between likelihood of survival or observed CSF changes and any individual llama or alpaca of the 54 included camelids. However, alpacas were subjectively more likely to survive to discharge from the hospital than llamas, and alpacas diagnosed with *P. tenuis* infestation were significantly more likely to survive to discharge than llamas with this diagnosis. Among camelids in which blood contamination was reported on CSF analysis, alpacas were significantly more likely to survive to discharge than llamas if the concentration of erythrocytes in the CSF was ≤13 200 cells/μL. The fact that this result is below the cutoff for considering CSF variables to be falsely increased by contamination further suggests the higher likelihood of survival in alpacas, because the presence of blood contamination should not affect survival status in this population.12 This observation is consistent with a previous study of 20 camelids, which found that the mortality rate of *P. tenuis* infestation was significantly higher in llamas compared to alpacas despite similar incidence of the disease.16 In both our study and the previous study, the study population included more alpacas than llamas, and thus these observations may reflect demographics and value perception of South American camelids favoring alpacas over llamas. This hypothesis is supported by the fact that the ratio of alpacas to llamas among the camelids included in our study is comparable to that observed in the general population of camelids seen at the Veterinary Health Center during the time period studied. Our study did not take into account the rationale given by owners who elected euthanasia, and cases in which camelids were euthanized because of a lack of financial resources to continue treatment could not be differentiated from cases in which euthanasia was elected because of poor prognosis or quality of life concerns.
In llamas, TNCC ≥ 3 cells/μL and percentage of eosinophils ≥ 10% were subjectively associated with decreased odds of survival to discharge. By contrast, in alpacas, no association was found between any CSF results and likelihood of survival. Previous studies on normal CSF results in South American camelids have focused on llamas, with the results extrapolated to alpacas. We could find no research that specifically documented normal CSF results in alpacas.\(^{11,17}\) It is possible that a higher association between CSF findings and survival was seen in llamas than alpacas because the previously established CSF reference ranges for these species were based on studies of llamas. Further research is needed to determine if and how these ranges differ in alpacas. However, the majority of alpacas included in our study survived to discharge, which may have impacted the results because the sample size for non-surviving alpacas was low.

Previous studies have established that, although increases in CSF variables may be suggestive of neurologic disease, they are not necessarily diagnostic. For example, a study that experimentally infected llamas with *P. tenuis* did not establish any consistent abnormalities associated with infection.\(^{18}\) A study in cattle diagnosed with astrovirus-associated encephalitis found increases in TNCC in 80% (4/5) of samples, whereas CSF TPC was only increased in 60% (3/5), emphasizing the variation possible in CSF variables.\(^{19}\) Although CSF eosinophilia has been established as a sensitive and specific method of antemortem diagnosis of *P. tenuis* infestation, the results of CSF cytology may vary among affected animals because of differences in parasite burden, stage of infestation, and prior treatment, making interpretation of results difficult.\(^{2}\)

Additionally, the fact that 51.9% (28/54) of samples included in our study were reported to have blood contamination, with 14.81% (8/54) of the samples having erythrocyte concentrations above the threshold for contributing to increased TNCC and TPC, suggests some results may have been false positives. Because blood contamination was such a common finding and was distributed between both groups of camelids, it was deemed unlikely to impact the results of our study. It is possible however that blood contamination could have masked the effect of TNCC, TPC, and percentage of eosinophils on survival to discharge. Blood contamination has been identified as a common finding on CSF analysis in camelids, but may be difficult to distinguish from hemorrhage caused by *Parelaphostrongylus* larvae migrating through the spinal cord, as has been reported in cases of *P. tenuis* infestation.\(^{1,20}\) In our study, 2 camelids had blood contamination reported in their CSF analysis, but the gross and histologic findings on necropsy in these animals were more consistent with non-sampling-associated hemorrhage. Histology may have been useful to distinguish blood contamination from hemorrhage, such as by detecting erythropagocytosis or hemosiderin and hematoidin within macrophages, but this information was not consistently available in included camelids.\(^{12}\)

Based on clinical signs of neurologic disease and CSF eosinophilia, the majority of camelids included in our study received a presumptive diagnosis of *P. tenuis* infestation. It could not be determined if the presenting complaints of any camelids in our study were caused by infestation with *P. tenuis* or what stage of disease they may have had at the time of sampling. The only established method of definitive diagnosis of *P. tenuis* infestation is the detection of larvae on necropsy, and false negatives are possible even at necropsy.\(^{2,21}\) Because of the retrospective nature of our study, in which camelids were included on the basis of CSF analysis alone, necropsy data was only available for 16.7% of included camelids (9/54).

Camelids also may be affected by disease processes other than *P. tenuis* infestation for which neurologic or neurologic-like signs may be observed and for which CSF analysis may be used to presumptively rule in or out *P. tenuis* infestation. However, the results of analysis may be nonspecific. Multiple disease processes can produce similar findings on CSF analysis. In 1 study of CSF findings associated with different diseases in ruminants, a mononuclear pleocytosis was observed in animals that were definitively diagnosed with a variety of different conditions, including listeriosis, rabies, polioencephalomalacia, and bovine herpesvirus 5.\(^{8}\) In our study, 46.3% (25/54) of included camelids were presumptively or definitively diagnosed with diseases other than *P. tenuis* infestation, including bacterial meningomyelitis and listeriosis. These findings may not be associated with some or all of the expected increases in CSF results. Further research is necessary to establish associations between abnormal increases in CSF variables and specific disease processes in camelids.

In addition, 13% (7/54) of included camelids were reported as having normal CSF on collection because all variables were within normal limits or only slightly increased. These animals were presumptively or definitively diagnosed with non-neurologic diseases, including arthritis, neoplasia, pneumonia, and renal failure. These findings suggest that obtaining normal results on CSF analysis may be helpful in localizing the source of clinical signs in camelids to systems other than the nervous system. However, false negative results for the diagnosis of neurologic disease cannot be ruled out. Furthermore, there are also neurologic disease processes in camelids for which a CSF analysis would not provide diagnostic information. For example, toxicosis and metabolic disease have been reported in camelids but are not associated with changes in CSF, and radiography or other imaging techniques are necessary to localize traumatic lesions.\(^{3,10}\) Although CSF analysis can help rule out other differential diagnoses in these cases, further information would be necessary to reach a definitive diagnosis.

Long-term survival data was not available for most animals included in our study, and it was deemed impractical to survey owners because of the time lapse between when the animals were examined and when the data were analyzed. As such, only short-term survival to discharge from the hospital was considered, and it is unknown how long camelids survived after discharge. Listeriosis and *P. tenuis* infestation in camelids may require prolonged treatment and have been associated with persistent neurologic deficits after recovery. It could not be assessed if any such deficits were noted in the surviving camelids in our study, or if subsequent treatments were performed.\(^{3,10}\) Camelids that did exhibit these deficits would likely be at a higher risk of culling or euthanasia than camelids that did not show persistent neurologic deficits because of quality of life and production concerns, as well as the increased cost associated with long-term care.

Neurologic diseases such as *P. tenuis* infestation can have a marked impact on the health of South American camelids. As a
diagnostic test, CSF can be collected and analyzed with relative ease, and our study provides further evidence that the presence of an increased TNCC on CSF is an important negative prognostic indicator for short-term survival. It must be emphasized however that many diseases only can be diagnosed presumptively based on CSF analysis, and the animal’s history, environment, and clinical presentation also must be considered when assessing prognosis.

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CONFLICT OF INTEREST DECLARATION
Authors declare no conflict of interest.

OFF-LABEL ANTIMICROBIAL DECLARATION
Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION
Approval for use of data in medical records was granted by the University of Missouri Veterinary Health Center.

HUMAN ETHICS APPROVAL DECLARATION
Authors declare human ethics approval was not needed for this study.

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