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A retrospective study of brain lesions in goats submitted to three veterinary diagnostic laboratories

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Abstract. A retrospective study of brain lesions in goats was conducted to identify the range of lesions and diseases recognized and to make recommendations regarding the best tissues to examine and tests to conduct in order to maximize the likelihood of making a definitive diagnosis in goats that may have had clinical signs referable to the brain. One hundred thirty-nine goats with a brain lesion were identified. The most common lesion, in 52.5% of the goats, was suppurative inflammation. Approximately two-thirds of these goats had encephalitic listeriosis. Other goats were found to have suppurative inflammation in association with septicemia, pituitary abscesses, dehorning injury, and otitis. Thirty goats (21.6%) were diagnosed with polioencephalomalacia. Twenty-one goats (15.1%) were diagnosed with nonsuppurative inflammation. In more than half of these goats, no definitive diagnosis was made, while 8 were infected with *Caprine arthritis encephalitis virus* and 1 with *Rabies virus*. However, few goats were tested for rabies. Based on these findings, it is recommended that, in addition to appropriate handling of the brain, the head should be examined with attention paid to the sella turcica and the temporal bones for evidence of a pituitary abscess and otitis, respectively. Histologic examination should include multiple areas of the brain, including the brainstem, for lesions of encephalic listeriosis; the cerebral cortex, for lesions of polioencephalomalacia; and the hippocampus, for Negri bodies associated with *Rabies virus* infection. Consideration should be given to collecting samples of other tissues including, but not limited to, the spinal cord and liver for ancillary testing if warranted.

Key words: Brain lesions; goats.

Introduction

According to the Food and Agriculture Organization of the United Nations, approximately 0.3% of the goats in the world are resident in North America.[19] This relatively low proportion may help to explain why goat diseases and caprine practice do not receive the same attention as other animal species and other types of practice, respectively, in the North American veterinary curricula and literature. Furthermore, a previous publication[19] reported that only 5% of goats submitted to diagnostic laboratories in North America had neurologic disease. For these reasons, a retrospective study of brain lesions in goats was conducted to identify the range of lesions and diseases recognized and to make recommendations regarding the best tissues to examine and tests to conduct in order to maximize the likelihood of arriving at a definitive etiologic diagnosis in goats that may have had clinical signs referable to the brain. A similar study describing lesions and diseases found in the spinal cord of goats was published in 2012.[1]

Materials and methods

A computer-assisted search of the records of 3 veterinary diagnostic laboratories—the Oregon State University Veterinary Diagnostic Laboratory in Corvallis, Oregon (OSU); Prairie Diagnostic Services Inc. in both Regina, Saskatchewan, and at the University of Saskatchewan in Saskatoon, Saskatchewan (PDS); and the University of Minnesota Veterinary Diagnostic Laboratory in St. Paul, Minnesota (UMN)—was conducted to identify the diagnostic reports of goats, greater than 1 week of age, that had been diagnosed with lesions of the brain during the 10-year period between January 2001 and December 2010, inclusive. Each diagnostic report was retrieved and reviewed. The diagnostic reports included the findings of the examination of both whole carcasses and portions of carcasses, hereafter referred to as portions. Those cases in which there was an unequivocal lesion in the brain were selected for further review. For each report, the year and month of submission; the age, sex, and breed of the goat; and the morphologic changes in the brain were

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summarized. Reports of goats with similar morphologic changes were grouped together. Then, the results reported for any ancillary tests, including the results reported for retrospective immunohistochemical testing for *Listeria*, were reviewed. Goats that were greater than 1 week of age, but less than a full month of age, were classified as 0.5 months of age. Fisher exact test and chi-square tests were performed using commercial software.[a]

Results

One hundred thirty-nine goats with a brain lesion were identified. Of these 139 goats, 46 (33.1%) were examined at OSU, 36 (25.9%) were examined at PDS, and 57 (41.0%) were examined at UMN. The mean and median number of goats with brain lesions examined each year was 13.9 (SD = 3.2) and 15, respectively, with a minimum of 6 goats examined in 2007 and maximum of 18 goats examined in 2006. Fewer goats, 27 or 19.4%, were examined during the winter months (Dec–Feb), compared to the spring (34 goats or 24.5%; Mar–May), summer (40 goats or 28.8%; Jun–Aug), and autumn (38 goats or 27.3%; Sep–Nov) months.

The age for 116 goats was specified and ranged from 0.5 to 120 months with a mean and median of 28 (SD = 26.3) and 24 months, respectively. Eleven goats were described only as adults, while the age of 12 goats was not specified. The 139 goats included 86 (61.9%) females, 28 (20.1%) males, and 10 (7.2%) castrated males. For 15 (10.8%) goats, the sex was not specified. The breeds of 139 goats were specified and are listed in Table 1.

The most commonly diagnosed brain lesion described in the reports reviewed (73 of 139 or 52.5%) was mixed inflammatory cell encephalitis, meningitis, or both (Table 2). A key feature of these lesions was the presence of neutrophils within the population of inflammatory cells that was interpreted as suppurative or pyogranulomatous inflammation. Several subtypes of suppurative and pyogranulomatous inflammation could be identified.

The most common subtype was suppurative or pyogranulomatous inflammation and foci of parenchymal necrosis restricted to, or centered on, the brainstem (i.e., the medulla oblongata, pons, and midbrain). Fifty such cases were identified, and all (100%) were diagnosed as listeriosis (i.e., infection with *Listeria monocytogenes*). Confirmation of the diagnosis was based on the results of bacterial culture, immunohistochemical staining (IHC), or both, on portions of the brain. Bacterial culture was performed as part of the original diagnostic investigation in 37 cases, with *L. monocytogenes* isolated in 33 (89%). Immunohistochemical staining was performed in 28 cases. In 13 of the 28 cases, IHC was performed as part of the original diagnostic investigation, and in the other 15 cases, IHC was performed retrospectively as part of the current study. Immunohistochemical staining detected antigens of *Listeria* in 25 of these 28 cases. In 15 of the 50 cases of encephalitic listeriosis, both bacterial culture and IHC were performed. In 8 of these 15 cases, *L. monocytogenes* was isolated, and antigens of *Listeria* were identified using IHC.

Table 1. The breeds of 139 goats with brain lesions examined at 3 veterinary diagnostic laboratories between 2001 and 2010, inclusive.*

Breed	No. of goats
Boer	33 (23.7)
Not specified	30 (21.6)
Mixed breed	22 (15.8)
Pygmy	14 (10.1)
Anglo-Nubian (syn. Nubian)	11 (7.9)
French-Alpine (syn. Alpine)	9 (6.5)
LaMancha	4 (2.9)
Angora	4 (2.9)
Nigerian Dwarf	4 (2.9)
Toggenburg	4 (2.9)
Saanen	2 (1.4)
Oberhasli	1 (0.7)
Tennessee Fainting	1 (0.7)
Total	139 (100.0)

* Numbers in parentheses are percentages. The 3 diagnostic laboratories are as follows: the Oregon State University Veterinary Diagnostic Laboratory in Corvallis, Oregon; Prairie Diagnostic Services Inc. in both Regina, Saskatchewan, and at the University of Saskatchewan in Saskatoon, Saskatchewan; and the University of Minnesota Veterinary Diagnostic Laboratory in St. Paul, Minnesota.

Table 2. The number and proportion of goats with various brain lesions and diseases diagnosed at 3 veterinary diagnostic laboratories between 2001 and 2010, inclusive.*

Lesion/disease	No. of cases
Suppurative encephalitis, meningitis, or both	73 (52.5)
Listeriosis	50
Other	
Extensive to diffuse inflammation	12
Focal inflammation	11
Polioencephalomalacia	30 (21.6)
Nonsuppurative encephalitis, meningitis, or both	21 (15.1)
No specific or etiologic diagnosis	12
Caprine arthritis encephalitis virus infection	8
Rabies virus infection	1
Other	15 (10.8)
Degeneration associated with copper deficiency	4
Spongiosis	4
Tumor/neoplasia	3
Familial storage disease	2
Parasite migration	2
Total	139 (100.0)

* Numbers in parentheses are percentages. The 3 diagnostic laboratories are as follows: the Oregon State University Veterinary Diagnostic Laboratory in Corvallis, Oregon; Prairie Diagnostic Services Inc. in both Regina, Saskatchewan, and at the University of Saskatchewan in Saskatoon, Saskatchewan; and the University of Minnesota Veterinary Diagnostic Laboratory in St. Paul, Minnesota.

In the 4 cases of encephalitic listeriosis in which *L. monocytogenes* was not cultured, antigens of *Listeria* were detected using IHC. In the 3 cases in which IHC failed to detect antigens of *Listeria*, the bacterium was cultured.

Sixteen (32.0%) goats diagnosed with encephalitic listeriosis were examined at OSU, 15 (30.0%) were examined at PDS, and 19 (38.0%) were examined at UMN; the mean and median number of cases diagnosed in each year was 5 (SD = 1.8), with a minimum and maximum of 2 and 8, respectively. While fewer cases, 21 or 42%, of encephalitic listeriosis were diagnosed during the winter (14) and spring (7) than during the summer (13) and fall (16), 29 or 58%, statistical analysis of these numbers using a Fisher exact test—with all other goats with diagnoses other than encephalitic listeriosis serving as the reference group—did not reveal a significant value ($P = 0.86$).

The age of goats diagnosed with encephalitic listeriosis was specified in 40 cases and ranged from 1.5 to 96 months, with a mean and median of 29 (SD = 21.9) and 24 months, respectively. Six additional goats were identified as adults, and the age of 4 goats was not specified. Thirty-one (62.0%) goats with encephalitic listeriosis were female, 9 (18.0%) were male, 4 (8.0%) were castrated males, and the sex was not specified for 6 (12.0%) of the goats. The breed of goats most commonly diagnosed with encephalitic listeriosis was similar, in proportion, to goats in the study (i.e., 15 [30%] were Boer, 10 [20%] were not specified, 8 [16%] were mixed, and 5 [10%] were Nubian; see Table 1).

In every case, the suspicion of encephalitic listeriosis was based on the nature and distribution of the inflammation. In 26 of the 50 cases (52%), the pathologist who examined the brain histologically used the word *microabscess* to describe a feature of the inflammatory response. In addition, the pathologist commented on the presence of bacteria within lesions in hematoxylin and eosin–stained histologic sections in 4 cases, and in 10 cases, the pathologist was able to identify short, Gram-positive bacilli. Six of the 50 goats dying of encephalitic listeriosis were diagnosed with an acute bronchopneumonia that was interpreted to be aspiration pneumonia.

Other subtypes of suppurative and pyogranulomatous inflammation of the brain could be divided based on the distribution of the inflammation into poorly delineated, extensive to diffuse lesions or relatively small, focal (or localized) to multifocal lesions (Table 2). There were 12 goats with poorly delineated, extensive to diffuse, suppurative or pyogranulomatous inflammation of the brain. The age of these goats was specified in 9 cases and ranged from 2 to 60 months, with a mean of 17.2 (SD = 18.3) months. A tenth goat was reported to be an adult. Bacterial culture of the brain was attempted in 8 cases, and *Arcanobacterium pyogenes* was isolated in 4; streptococci were isolated twice, and no bacteria were cultured in 2 cases. Of the 6 cases in which bacteria were isolated from the brain, the same bacteria were isolated from other organs, most commonly the lungs, in 4 cases. This finding was interpreted as evidence of septicemia.

The remaining 11 goats with suppurative or pyogranulomatous inflammation of the brain had relatively small, focal or multifocal lesions. Of these, 4 had pituitary abscesses, 3 had 1 or 2 focal lesions deep to lesions of the horn buds and frontal bones, 3 had lesions of the brainstem and concurrent otitis media, and 1 had an intracranial abscess over the cerebral cortex. The age of 3 goats with a pituitary abscess was known; 1 was 10 months and 2 were 12 months. The fourth goat was described as an adult. Bacterial cultures were performed on material from each of the pituitary abscesses, and *A. pyogenes* was isolated in 2 cases while *Corynebacterium pseudotuberculosis* and *Staphylococcus aureus* were isolated from 1 case each.

All 3 goats with encephalitis, meningitis, or both, that was related to lesions deep to the horn buds and frontal bones were 2 months of age. In contrast, the 3 goats with otitis media were 24 months, 30 months, and an adult. Both *A. pyogenes* (3 times) and *C. pseudotuberculosis* (2 times) were isolated, sometimes with other bacteria, from these lesions.

The second most commonly diagnosed brain lesion described in the reports reviewed for the present study (30/139, 21.6%) was necrosis of neurons within the cerebral cortex with no, or very minimal, inflammation. When present, the inflammation was uniformly nonsuppurative. The pathologists summarizing these cases interpreted their findings as polioencephalomalacia (PEM) in 23 cases; as laminar cerebrocortical necrosis, or more simply as cerebral cortical necrosis, in 5 cases; or both PEM and cerebral cortical necrosis in 2 cases.

Sixteen (53.3%) goats diagnosed with PEM were examined at OSU, 10 (33.3%) were examined at PDS, and only 4 (13.3%) were examined at UMN, a distribution significantly different ($P < 0.01$), using a chi-square test, from the distribution of all other goats with other diagnoses. The mean number of cases diagnosed in each year was 3 (SD = 1.9), and the median was 2, with a minimum and maximum of 0 and 6, respectively. The seasonal distribution of cases of PEM was tested, using a chi-square test, and found to be similar ($P = 0.87$) to that of all other goats with diagnoses other than PEM serving as the reference group. The fewest cases were diagnosed during the winter months.

The age of goats diagnosed with PEM was specified in 25 cases and ranged from 0.5 to 120 months, with a mean and median of 36.6 (SD = 30.7) and 30 months, respectively. One additional goat was identified as an adult, and the age of 4 goats was not specified. Twenty (66.7%) goats with PEM were female, 5 (16.7%) were male, 2 (6.7%) were castrated males, and the sex was not specified for 3 (10%) of the goats. The breeds of goats most commonly diagnosed with PEM were similar, in proportion, to goats in the study (5 [16.7%] were Boer, 5 [16.7%] were mixed, and 3 each [10%] were Nubian or Angora; see Table 1) except that a higher proportion of goats, 11 or 36.7%, were of unknown breed.

The pathologists conducting the original investigation described the results of examining the "fresh" (i.e., unfixed) or formalin-fixed brain under ultraviolet light in 17 cases and

reported seeing fluorescence in 13 (76.5%) cases. Four goats diagnosed with PEM were found to have a concurrent, acute, bronchopneumonia that was interpreted to be aspiration pneumonia.

The third most commonly diagnosed brain lesion described in the reports reviewed in the present study (21/139, 15.1%) was nonsuppurative encephalitis, meningitis, or both (Table 2). The key feature of these lesions was the presence of inflammatory cells, such as lymphocytes, plasma cells, or macrophages, in the absence or near absence of neutrophils.

Of the 21 goats diagnosed with nonsuppurative inflammation, none were examined at OSU, 2 (9.5%) were examined at PDS, and 19 (90.5%) were examined at UMN, a distribution significantly different ($P < 0.01$) than all other goats with a different diagnosis. The mean number of cases diagnosed in each year was 2.1 (SD = 1.3), the median was 2, and the minimum and maximum were 0 and 4, respectively. Fewer cases were diagnosed during the winter and spring months (3 and 4, respectively) than during the summer and fall (7 each).

The age of goats diagnosed with nonsuppurative encephalitis, meningitis, or both was specified in 18 cases and ranged from 2 to 60 months, with a mean and median of 20.1 (SD = 18.2) and 14 months, respectively. One goat was identified as an adult, and the age of 2 goats was not specified. Nine (42.9%) goats with nonsuppurative inflammation were female, 4 (19.0%) were male, 3 (14.3%) were castrated males, and the sex was not specified for 5 (23.8%) of the goats. The breeds of goats most commonly diagnosed with nonsuppurative inflammation included Pygmy (6, 28.6%) and Nigerian Dwarf (3, 14.3%).

Ancillary testing was performed on 17 of the 21 cases of nonsuppurative inflammation. Some combination of serologic, IHC, or polymerase chain reaction testing for the presence of *Caprine arthritis encephalitis virus* (CAEV) was performed on 11 cases, all from UMN, and evidence of CAEV was detected in 8 cases. Testing for *Rabies virus* (RABV) was performed in 8 cases, 2 from PDS and 6 from UMN, and a RABV infection was confirmed in 1 of the animals examined at PDS. The method of testing for RABV was not always described, but fluorescent antibody and IHC were each used. Other methods, such as bacterial culture, virus isolation, and IHC, did not identify any other pathogenic microorganisms such as *Listeria* and *Toxoplasma*. Overall, the cause of the nonsuppurative inflammation was determined in less than half of the cases (i.e., in 12 cases no etiologic diagnosis was made).

All 8 of the goats diagnosed with CAEV were examined at UMN between 2001 and 2006, inclusive. The ages of 7 of these goats were known and were 2, 3.5, 5, 24, 30, 36, and 60 months, with 1 additional goat described as an adult. In contrast to the proportion of 3 female goats to 1 male goat in the study population, there were equal numbers of female and male goats affected with CAEV. Also, unlike the study population, none of the goats with CAEV were Boers; 3 were Pygmy goats, 2 were Toggenburg, and there was 1 Alpine, mixed breed, and Nigerian Dwarf each. None of these goats appeared to be from the same farm.

The remaining 15 (10.8%) goats in the current study were diagnosed with a variety of brain lesions or diseases (see Table 2). Four goats were found to have neuronal degeneration, in the form of chromatolysis, neuronal necrosis, or both, in some combination of the cerebral cortex, brainstem, or cerebellum. These changes were not associated with inflammation. Hepatic copper analysis was conducted in 3 of these goats and found to be 3.3 ppm in a 3-month-old, male Boer goat examined at PDS; 9 ppm in a 2-month-old, male Boer goat examined at OSU; and 12.7 ppm in a 36-month-old, female Pygmy goat examined at UMN.

The brain of 4 other goats had a vacuolated or spongy appearance. Two of these goats, a 60-month-old, female Nubian goat examined at OSU and a 2.5-month-old, female goat of unspecified breed examined at PDS, were diagnosed with hepatic encephalopathy based on a concurrent hepatic microangiopathy and severe hepatic lipidosis, respectively. Two other goats, a 4.5-month-old, female goat of unspecified breed examined at PDS and a 72-month-old, female goat of unspecified breed examined at UMN, with vacuolation or spongiosis of the brain were diagnosed as having brain edema with no underlying cause for the brain lesion identified.

Three goats were diagnosed with encephalic tumors. Two goats, a 60-month-old, castrated male Nubian goat examined at OSU and a 36-month-old, female goat of unspecified breed examined at UMN, were diagnosed with multicentric lymphoma that involved the brain. The third goat, a 108-month-old, female Pygmy goat examined at OSU, was found to have a 2-cm-diameter, polypoid mass within the dilated right lateral ventricle. A choroid plexus tumor was suspected, but due to client financial restraints, histologic evaluation of the mass was not pursued.

Two Boer goats, approximately 0.5 and 2 months of age, were examined at OSU and were diagnosed with a congenital, and possibly familial, neuronal anomaly. Neurons in both the brain and spinal cord of these goats had a granular or finely vacuolated appearance when examined by routine light microscopy. Electron microscopy revealed increased numbers of mitochondria, many of which were enlarged.

Finally, 2 goats examined at UMN had a combination of hemorrhage, foci of necrosis, microcavitation, nonsuppurative inflammation, and, in 1 case, nematode larvae present in the brainstem. Both of these goats were mature, 48 months and 108 months of age, females. One goat was an Alpine and the other was a Pygmy.

Discussion

Most of the brain lesions identified in the diagnostic reports reviewed for the present study (94/139, 67.6%) were those of inflammation. In a comparable study of Swiss fallen stock,

the same proportion of goat brains with lesions featured inflammation.[13] While a variety of exogenous and endogenous substances are capable of inducing an inflammatory response, a useful principle of neuropathology is that bacterial infections are associated with suppurative inflammation while viral infections are associated with nonsuppurative inflammation.[9,13,21] Fifty cases of suppurative to pyogranulomatous inflammation that were restricted to, or centered on, the brainstem were identified. Based on the character and distribution of the inflammation, the pathologist conducting the original diagnostic investigation considered infection by *L. monocytogenes* as a possible cause of the lesions. In every case, the diagnosis was corroborated through bacterial culture, IHC, or both, of the brainstem, with IHC being performed as part of the current study in some cases.

Bacterial culture and IHC for *Listeria* was performed in other cases of encephalitis, meningitis, or both, but the bacterium was not identified. Review of these cases revealed that the inflammatory response either lacked neutrophils or extended well beyond the brainstem, typically involving the cerebrum. Based on these findings, it appears that there are currently no known differential etiologies for suppurative to pyogranulomatous inflammation with foci of parenchymal necrosis restricted to, or centered on, the brainstem of goats. This information supports the opinion of other authors reviewing encephalitic listeriosis in ruminants who have stated that the histologic lesions of severe, often asymmetric, foci of mixed cellular inflammation, including microabscesses, malacia, and perivascular infiltration of mononuclear inflammatory cells of the medulla oblongata, pons, and, less often, other parts of the midbrain and cervical spinal cord, are pathognomonic.[2,8,24] In contrast, in a 2010 published study of encephalitic listeriosis of ruminants from Switzerland, the authors concluded that the inflammatory lesions are not restricted to the medulla and pons in most animals. Rather, inflammatory lesions were commonly found in more rostral aspects of the brain.[14] Nevertheless, the more rostral lesions were less frequent, less severe, and appeared to develop later in the course of the disease compared to the inflammatory lesions in the brain stem.

Despite these opinions, many of the pathologists investigating goats included in the present study attempted to confirm the presence of *Listeria* by way of bacterial culture, IHC, or both. There are few reports detailing the rate of successful isolation of *L. monocytogenes* from the brain of affected goats. In 2 such studies involving a relatively small number of cases, the bacterium was isolated in 11 of 12 (91.7%) cases[5] and 10 of 13 (76.9%) cases.[6] In the current study, *L. monocytogenes* was isolated in 33 of 37 (89.2%) cases. While the relatively high rate of isolation of *L. monocytogenes* from cases of encephalitic listeriosis in goats is encouraging, it must be emphasized that isolation can be difficult and may be unsuccessful, is expensive because it often requires special procedures, and may require several weeks to several months to achieve.[20,24] These issues were experienced and commented on in several reports reviewed for this study.

Immunohistochemical staining, therefore, is a useful and often more rapid means of identifying *Listeria* within the lesions of suspected cases of encephalitic listeriosis. In a previous study, IHC was thought to confirm the presence of *Listeria* in the brain of 10 of 12 (83.3%) of tested goats.[5] However, in the 2 goats in which IHC failed to detect *Listeria*, bacterial culture had not been attempted and the diagnosis of encephalitic listeriosis was based solely on the nature of the lesions in the brainstem; specifically, listeriosis was never confirmed. In a second study, IHC detected the presence of *Listeria* in the brain of 100% of 3 goats from which *L. monocytogenes* had been isolated and in 2 of 3 (66.7%) goat brains with histologic lesions of listeriosis but from which *L. monocytogenes* could not be isolated after 12 weeks.[24] In the current study, IHC performed at the time of the original diagnostic investigation supported the presence of *L. monocytogenes* in 10 of 13 (76.9%) cases while IHC performed retrospectively identified *Listeria* in all 15 cases (100%), including 2 cases in which bacterial culture had been attempted but *L. monocytogenes* was not isolated.

It has been suggested that encephalitic listeriosis in goats, and other ruminants, is more common in winter and spring, presumably due to crowding associated with the feeding of silage and crowding associated with confinement.[20,21] The current study did not support this supposition, and it should be noted that most cases (60%) occurred in the fall and winter with the fewest cases diagnosed in the spring. The most important finding may be that encephalitic listeriosis was diagnosed in every month of the year with no apparent trend.

There are at least 2 publications in the veterinary literature describing a pituitary abscess syndrome in ruminants, including goats.[11,16] The pathogenesis of pituitary abscesses in ruminants is unknown, but it is believed to be the result of the hematogenous spread of bacteria from another area of the body. Collectively, a variety of bacteria, in pure and mixed cultures, have been isolated from pituitary abscesses of ruminants. However, the most commonly isolated bacterium is *Arcanobacterium pyogenes* (previously designated *Actinomyces pyogenes* and *Corynebacterium pyogenes*). Two of the 4 goats with pituitary abscesses in the current study had *A. pyogenes* isolated from the lesion. It has been suggested that male ruminants, intact and castrated, may develop pituitary abscesses more commonly than females.[11,16,21] However, among the animals included in a previous retrospective study involving domestic ruminants,[16] all 3 of the affected goats were female. In the current study, 2 goats were male and 2 were female.

Three goats in the current study, all 2 months of age, had 1 or 2 focal lesions of the cerebral cortex that included necrosis, thrombosis, and suppurative inflammation in association with lesions of the overlying horn bud and frontal bone. These findings are consistent with a disbudding injury[18,20,22] and were diagnosed as such by the investigating pathologist.

In at least 2 of these cases, the goat kid examined was 1 of several others goats of the same age on the same farm with a history of acute illness, sudden death, or both, suggesting other kids on the farm had similar lesions.

Three goats in the present study had inflammation of the brainstem that was concurrent with, and likely subsequent to, inflammation of the middle ear. There appears to be very few reports of otitis media, or otitis interna, of goats in the veterinary literature.[15] The 3 goats included in the current study were all mature (24 months or older). The pathogenesis of otitis media in other domestic ruminants is believed to involve arrival of pathogens in the middle ear by 1 of 3 routes: via the eustachian (auditory) tube, extension from the external ear following damage of the tympanic membrane, or hematogenously.[11]

Other cases of suppurative inflammation of the brain were the result of hematogenous spread of bacteria leading to extensive to diffuse suppurative inflammation. In several of these situations, *A. pyogenes* was isolated from the lesion. *Arcanobacterium pyogenes* is a common commensal of ruminants, and a relatively recent review suggests that *A. pyogenes* is capable of acting as a primary pathogen.[7] However, *A. pyogenes* has long been regarded as an opportunistic pathogen able to proliferate and disseminate following damage to colonized skin and mucus membranes.[7] It is worth noting that there were few, if any, cases of suppurative inflammation of the brain associated with neonatal septicemia.[15,20,21] This is likely due to the selection criteria used in this study (i.e., that only goats older than 1 week of age were included).

There appears to be very few published cases or studies of PEM in goats in the veterinary literature, particularly over the past 25 years. What are believed to be the causes and the pathogeneses of PEM in goats is based on knowledge derived from cattle and sheep. Polioencephalomalacia in ruminants occurs in association with a functional thiamine (vitamin B_1) deficiency, sulfur toxicosis, water deprivation–salt toxicity, lead poisoning, and hypoxia.[4,15,21] In the present study, 30 (21.6%) goats were diagnosed with PEM, but a cause for the lesion was not determined in any of the cases. In only 1 case of PEM was a test conducted to determine tissue lead concentrations. This may seem inadequate, but at the same time, a previous publication[19,20] reported that there are no documented cases of naturally occurring lead poisoning in goats in the contemporary literature. The authors then go on to argue that goats may have an innate resistance to the effects of lead and may be less likely to consume sources of lead.

It is not known why more than 50% of the goats with PEM in the current study were examined at OSU and approximately 13% were examined at UMN when only approximately 33% of all goats in the present study were examined at OSU and more than 40% were examined at UMN. A more detailed investigation into feeding and other management practices, as well as the quality of available water, may be insightful. It is also worth considering that weather may have an indirect role in the large proportion of goats diagnosed with PEM at OSU. Oregon has a temperate climate, and the Willamette Valley region experiences heavy rainfalls in winter and spring. Many goats submitted to OSU for postmortem examination originate from the Willamette Valley.[23] Because mild temperatures and high environmental moisture promote survival and development of coccidia,[19,23] goat producers may be more likely to administer sulfonamides, amprolium, and other products to prevent and treat coccidiosis in goats.[10,19] However, orally administered antibiotics, amprolium, and other products are believed to contribute to the development of PEM in ruminants.[4]

Twenty-one (15.1%) goats in the present study were diagnosed with nonsuppurative encephalitis, meningitis, or both. Over 90% of these goats were examined at UMN and none were examined at OSU, a pattern similar to that reported for spinal cord lesions.[1] The reason or reasons behind this distribution is not certain. However, a CAEV infection was confirmed in 8 of 19 (42.1%) goats examined at UMN and suspected in several others. Therefore, part of the explanation for the distribution of cases involves the presence of CAEV in the goat herds around UMN and an apparent absence of CAEV in goat herds around OSU. Other viruses, namely RABV, *Suid herpesvirus 1*, *Border disease virus*, *Borna disease virus*, and *Louping ill virus* have all been diagnosed in goats, although uncommonly,[3,15,19] and while ruminants appear to be far less susceptible to *West Nile virus* infection and disease than horses, *West Nile virus* infection should remain a differential diagnosis in goats with nonsuppurative meningoencephalomyelitis for which no other diagnosis has been established. Of the 12 cases of nonsuppurative encephalitis, meningitis, or both, in which no etiologic diagnosis was made, 8 were tested for RABV infection. One goat with nonsuppurative encephalitis examined at PDS was diagnosed with rabies.

Small numbers of goats were diagnosed with 1 of several other lesions and diseases. These conditions have been previously discussed in a similar study of spinal cord lesions in goats.[1] More specifically, 4 goats were diagnosed with degeneration associated with copper deficiency that is more commonly referred to as copper deficiency myelopathy, swayback, or enzootic ataxia. Three of these 4 goats had their hepatic copper concentrations determined (3.3, 9.0, and 12.7 ppm, respectively); each was below the reference interval of 25–150 ppm.[17] For the fourth goat, a 3-month-old, the dam had been diagnosed with low serum copper concentrations.

Four goats were also found to have vacuolation or spongiosis of the brain. Two of these goats were diagnosed with hepatic encephalopathy, owing to concurrent hepatic lesions,[21] while the 2 others were diagnosed as having brain edema as no underlying cause for the brain lesion was identified. It should be stressed that the term *spongiosis* was used in these 2 cases as a descriptor of the spongy or vacuolated appearance of the brain evident during routine light microscopic

examination. This appearance may be the result of vacuoles within neuron and glial cell processes of the neuropil, vesiculation of myelin sheaths, or swelling of astrocyte or oligodendrocyte cytoplasm.[21] In these cases, the term *spongiosis* was not used to refer to the vacuolated appearance of neuronal perikaryon commonly present in the transmissible spongiform encephalopathies, such as bovine spongiform encephalopathy and scrapie, both of which have been diagnosed in goats, although with much less frequency than in cattle and sheep, respectively.[13,15,21] While scrapie is endemic in both Canada and the United States, no cases of scrapie were found among the goats included in the present study.

Two goats were diagnosed with lymphoma, 1 at OSU and 1 at UMN; 2 Boer goats examined at OSU were diagnosed with a congenital, and possibly familial, neuronal anomaly; and 2 goats, both examined at UMN, were found to have lesions consistent with parasite migration with the parasite believed to be the larvae of *Parelaphostrongylus tenuis*.[12,13,15,20] The reader is referred to a similar study describing lesions and diseases found in the spinal cord of goats for additional information.[1]

Based on the present results, the following recommendations are offered to owners, practicing veterinarians, and diagnostic veterinary pathologists interested in optimizing the investigation of the cause of clinical signs referable to the brain in naturally dying or euthanized goats. First and obviously, the brain should be examined, and efforts should be made to preserve it at the time of examination. Ideally, the brain should be removed from the carcass and kept cool, not frozen if possible, and submitted to a diagnostic lab as quickly as is reasonable. In situations where submission of the brain to the diagnostic lab may be delayed or may result in physical damage, it should be hemisectioned along the midsagittal plane and half the brain fixed in 10% neutral buffered formalin and half refrigerated or frozen. It is acknowledged that outside of a diagnostic laboratory, the postmortem removal of the brain may be difficult and time-consuming. In such situations, submission of the head or of the entire carcass is a logical alternative. The head or carcass should be kept cool and not frozen, if possible.

In several of the reports reviewed for the current study, the pathologist reported receiving several small portions of the brain, either fixed in formalin, unfixed, or both, to examine. It is assumed that the submitter sent small portions of the brain to reduce the volume and weight of the material submitted, thereby make packaging easier and shipping less expensive. However, these potential benefits are nullified if the portions of brain submitted do not contain the diagnostic lesion or are inappropriately preserved to allow for definitive ancillary testing.

Examination of the spinal cord can also be helpful in determining the cause of neurologic disease,[1] but the postmortem removal of the spinal cord from the vertebral column may be even more difficult and time-consuming than removing the brain from the skull. In such situations, submission of the entire carcass is a logical alternative, but again, the carcass should be kept cool and not frozen, if possible.

In the diagnostic investigation of at least 6 goats in the current study, examination or testing of the liver was, or would have been, required in order to make a definitive diagnosis. In addition to examining the brain, gross and histologic examination of the liver is necessary to diagnose hepatic encephalopathy, and analysis of the liver is required to determine the copper concentration. Therefore, it is recommended that an appropriate amount of liver, both fixed and unfixed, should also be collected to allow for both of these studies.

At least 14 goats included in the current study had diagnostically important lesions in the lungs. Six goats with encephalitic listeriosis and 4 goats with PEM had an acute bronchopneumonia that was interpreted to be aspiration pneumonia. Two goats had both a suppurative brain lesion and suppurative pneumonia caused by the same bacteria, and it was concluded that the brain lesions were sequelae of the pneumonia. Finally, 2 goats with CAEV infections had an interstitial pneumonia. Based on these findings, the gross and histologic examination of lungs appears to be important, and bacterial culture may be useful in the postmortem investigation of goats with a history of clinical signs referable to the brain.

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Sources and manufacturers

a. GraphPad Prism version 5.04 for Windows, GraphPad Software, San Diego, CA.

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