MORTALITY IN COQUEREL'S SIFAKAS (*PROPITHECUS COQUERELI*) UNDER HUMAN CARE: A RETROSPECTIVE SURVEY FROM THE DUKE LEMUR CENTER 1990–2015

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MORTALITY IN COQUEREL'S SIFAKAS (*PROPITHECUS COQUERELI*) UNDER HUMAN CARE: A RETROSPECTIVE SURVEY FROM THE DUKE LEMUR CENTER 1990–2015

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Abstract: Coquerel's sifakas (*Propithecus coquereli*) are diurnal, folivorous lemurs native to Madagascar and one of only two members of the genus *Propithecus* currently housed in human care settings outside of Madagascar. This species has a lifespan of approximately 30 yr but minimal information exists regarding morbidity and mortality in human care settings. In this retrospective study, medical records, postmortem exam, and autopsy reports from 56 animals housed at the Duke Lemur Center from 1990 to 2015 were evaluated. Mortality assessments included age, sex, time of year, histopathological findings, major organ system impacted, and etiological factors. Mortality was most prevalent among adults greater than 2 yr of age (42.9%) and neonates less than 7 days of age (30.4%). The top four morphological diagnoses accounted for 51.7% of all deaths and included stillbirths (19.6%), enteritis-colitis (12.5%), failure to thrive (10.7%), and systemic protozoal infections (8.9%). The two most commonly affected organ systems in animals over 7 days of age were multisystem disease (30.8%) and the gastrointestinal system (28.2%). Infections were the most common etiology with bacterial being the most prevalent followed by protozoal infections. The results provide insight into common causes of mortality of this species and can be used to guide management of this endangered primate and improve longevity in human care settings.

Key words: Coquerel's sifaka, lemur, mortality, *Propithecus coquereli,* prosimian.

INTRODUCTION

Madagascar is one of the top five biodiversity hotspots in the world due to the high number of endemic flora and fauna. Since humans arrived on the island approximately 2,000 years ago, over 90% of the native forests have been lost as a result of anthropogenic activities including burning forests for agriculture, rice cultivation, and cattle grazing.[16,25] These practices combined with severe poverty and political unrest have put a strain on the remaining natural resources and pose significant challenges to conservation efforts aimed at preserving the remaining biodiversity.[16,26]

Despite its relatively small land mass (e.g., less than 7% that of Brazil), Madagascar is home to 15% of all primate species and subspecies globally.[21] One hundred and three distinct species of lemurs are currently recognized, and 91% of those are threatened with extinction. In 2012, the International Union for the Conservation of Nature (IUCN) listed lemurs as the most endangered group of mammals on the planet.[12] As a result, programs aimed at maintaining and breeding various lemur species in human care have taken on a new urgency.

Coquerel's sifakas (*Propithecus coquereli*) are a medium-bodied diurnal lemur native to the dry-deciduous forests of northwestern Madagascar. Coquerel's sifakas are predominately folivorous and have a maximum recorded lifespan of approximately 30 yr in captive settings.[6,32] The IUCN lists these lemurs as Endangered with the population decreasing due to habitat loss and bush meat hunting.[22] Starting in the 1960s, a founding population of 16 Coquerel's sifakas was established at the Duke Lemur Center (DLC) in Durham, North Carolina, with the aim of establishing a breeding program as a hedge against extinction in the wild and the goal of developing husbandry protocols for the species (David Haring, pers. comm.).

Propithecus coquereli and *Propithecus coronatus* (crowned sifaka) are the only members of the genus *Propithecus* currently in human care outside of Madagascar.[11] Sixty-seven Coquerel's sifakas are housed in the United States at the time of this writing with 35 located at the DLC and 32 housed at various zoological institutions in North America.[11] Although Coquerel's sifakas have been in human care for over 50 yr there is a scarcity of information in the literature concerning diseases

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found in such settings. Mortality in wild populations is often attributed to predation, annual variation in resource availability, and infanticide; however, little information is available regarding the impact of disease on mortality in wild populations.[10] Despite a maximum recorded age of 30 yr in human care, the median age of mortality at the DLC in Coquerel's sifakas that live longer than 30 days is 10.3 yr.[32] A vital step towards improving longevity of Coquerel's sifakas in human care is developing a more complete understanding of the causes of mortality in the species in such environments..[5,22,23] This manuscript serves as a comprehensive review of mortality from natural causes in a population of Coquerel's sifakas at the Duke Lemur Center over a 26-yr period undertaken to better understand factors that contribute to mortality in human care and develop recommendations for improving medical care of the species. The findings provide insight into common causes of mortality for Coquerel's sifakas by age, time of year, organ system, and etiology.

MATERIALS AND METHODS

Animals

The study included 56 Coquerel's sifakas that died of natural causes or were euthanized due to terminal illness at the DLC. Medical records, including gross postmortem exam and histopathology reports from 1990 to 2015, were reviewed for 23 females (median 2.2 yr, range 0–21.7 yr) and 32 males (median 0.3 yr, range 0–30.6 yr). Sex was undetermined for an additional infant. Animals owned by the DLC that died on loan at other institutions were excluded. Fifty of the 56 animals in the study were born and died at the DLC and 6 were wild-born in Madagascar, arriving at the DLC between 1982 and 1986.

Animals were housed as family groups or pairs in several different enclosure types that changed over the study period. Enclosure designs included corn crib type outdoor silos with supplemental heat provided in the colder months; indoor climate-controlled rooms without outdoor access; and outdoor semi-free-ranging environments in fenced, multi-acre, forested enclosures during warm months of the year. Diets consisted of a commercially available primate biscuit (Mazuri Leaf-Eater Primate Diet Mini-Biscuit # 5672, Mazuri, PMI Nutrition International, St. Louis, Missouri 63166, USA) supplemented with vegetables, nuts, and fresh local browse.

Records

Data on the date of birth, date of death, and sex of all individuals was obtained from historical DLC records. In the case of wild-born animals, the DLC records included an estimate of the animal's age and year of birth at the time of capture with the month and day of birth assigned as 1 July, which corresponds with peak birth season in Madagascar.

Postmortem records were reviewed to determine a primary cause of death or pathological diagnosis, primary organ system affected, and etiology. Histopathology was performed at Roche Biomedical Laboratories (Burlington, North Carolina) from 1990 to 1998 and North Carolina State University College of Veterinary Medicine Histopathology Laboratories (Raleigh, North Carolina) from 1998 to 2015. Gross and microscopic postmortem exam reports were available for all animals with the exception of seven infants for which necropsies were not performed. In these cases, the dam's medical record was reviewed for information relevant to the case. Infants lacking postmortem data were classified as stillborn if they were dead when discovered at first morning check. Infants having postmortem exams performed were classified as stillborn if the lungs did not float in formalin, indicating the infant did not breathe following delivery.

All diagnoses listed on the histopathology reports were reviewed by an ACVP boarded veterinary pathologist (J. Cullen). Original glass slides were available for review for animals that died 1998 and later. For cases in which questions arose regarding the diagnosis or interpretation of findings by the pathologist originally reviewing the case, the original slides were reviewed to confirm or modify the interpretation and diagnosis. If the interpretation or diagnosis of the histopathology report differed based on the second review, a third pathologist reviewed the slides and the diagnosis supported by two of the three pathologists was used. In some cases, the cause of death or reason for euthanasia was evident in information contained in the gross postmortem exam report instead of the histopathology report (e.g., a case of trauma in which the severity of injury was not evident histopathologically but visible grossly). It was not possible to determine a cause of death in all cases despite the availability of gross postmortem exams, histopathology reports, and medical records.

Table 1. Demographic distribution of mortality by age group and sex for all Coquerel's sifakas in the study population.

Age class[a]	Total, $n = 56$ (%)	Female, $n = 23$	Male, $n = 32$	Unknown, $n = 1$
Perinatal	17 (30.4)	4	12	1
Infant	10 (17.9)	5	5	0
Juvenile	5 (8.9)	2	3	0
Adult	24 (42.9)	12	12	0

[a] Perinatal (≤7 days), infant (8–180 days), juvenile (6 mo to 2 yr), and adult (>2 yr).

Data analysis

Data used in the project were obtained from both original medical records and laboratory reports maintained by the DLC as well as digital files managed by the Zoological Information Management System (ZIMS) (Species 360, Bloomington, Minnesota 55425, USA).

Animals were categorized into four age groups to evaluate mortality at different life stages: perinatal (≤7 days), infant (8–180 days), juvenile (6 mo to 2 yr) and adult (>2 yr). Mortality was also evaluated by sex within each age group and by time of year in juveniles and adults. Mortality information collected included morphological or histopathological diagnosis, organ system affected, and etiological diagnosis.

Statistical analysis was performed using JMP Pro 12 (SAS, Cary, North Carolina 27513, USA). Data for sex, age at death, and month of death are provided as medians and ranges. Differences between sexes were determined using the two-sided chi-square test. The Wilcoxan and Kruskal-Wallis tests of rank sums were used to compare differences between groups with significance set at $P < 0.05$.

RESULTS

The study included 56 Coquerel's sifakas (23 females, 32 males, and 1 sex undetermined [ND]) with age at death ranging from 0 days to 30.6 yr (median = 1.3 yr). The distribution by age group is provided in Table 1.

There was no significant difference in mortality based on sex within any age group. Mortality in the adult age group accounted for the majority of deaths followed by the perinatal group. Sex was evenly distributed in all age classes with the exception of the perinatal group in which males outweighed females three to one; however, the difference was not statistically significant. All 17 deaths in the perinatal group occurred within the first 3 days of life with 11 of 17 (64.7%) classified as stillborn. Mortality in the perinatal and infant groups occurred exclusively December through July as would be expected given the seasonal nature of reproduction in North America in which the peak birth season is December to March. Mortality in the juvenile and adult groups was also highly seasonal with nearly two-thirds of deaths (65.5%) occurring April through July (Fig. 1).

Morphological diagnosis

Table 2 presents the morphological diagnosis of mortality in descending order of occurrence by age group. Stillbirth and failure to thrive (FTT) accounted for all but one death in the perinatal group. Stillborn males outnumbered females 10 to 1 and was significant at $P = 0.0035$. Four of the 11 stillbirths were classified as dystocia or fetal distress based on unusually large size of the fetus and/or bruising on the face, head, and/or surface of the brain at gross postmortem exam with or without evidence of aspiration of meconium or amniotic fluid in the lungs on histopathology. An etiology for the remaining seven stillborn infants could not be determined as necropsies were not performed, however 6 of 11 (54.5%) stillborn infants were born to primiparous females as determined by review of DLC historical husbandry records. All FTT deaths within the perinatal group occurred between 2–3 days of age and there was no relationship between parity of the dam and the incidence of infant death due to FTT.

In animals >7 days of age, in which a cause of death could be determined, enteritis-colitis, systemic protozoal diseases, and multi-organ suppurative necrosis were the top three morphological diagnoses and, combined, accounted for 38.5% of deaths. Multi-organ suppurative lesions were present in animals with septic infections due to *Listeria monocytogenes* or *Yersinia enterocolitica*.

In animals diagnosed with enteritis, one was further classified as acute suppurative necrotizing enteritis and the second had villous atrophy. Microscopically, colitis was further identified as lymphoplasmacytic in four cases and ulcerative in one.

Cryptosporidium organisms were seen microscopically in the intestinal mucosa of four animals with three individuals having lymphoplasmacytic infiltrates in the intestinal mucosa while the fourth had only mild edema of the mucosa. An additional animal with lymphoplasmacytic colitis was positive for *Clostridium difficile* toxoid A and B in feces. An additional two animals diagnosed

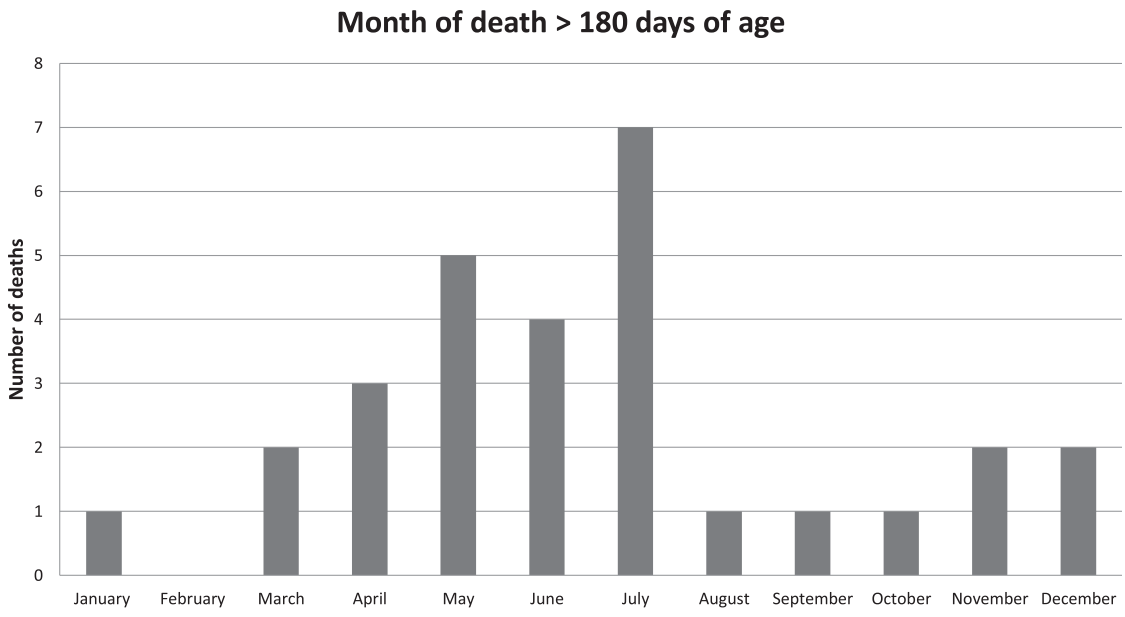

Figure 1. Mortality in lemurs >180 days of age depicting month of death ($n = 29$).

with systemic *Listeria* infections had ulcerative colitis or typhlocolitis in addition to suppurative lymphadenitis and hepatitis with microabscesses in liver parenchyma. Five animals with intestinal disease developed systemic bacterial infections that ultimately proved fatal. In four of the cases the diagnosis of sepsis was made via positive blood culture antemortem and the fifth via culture of kidney tissue immediately postmortem. A sixth animal had microvascular thrombi in the liver and lungs consistent with disseminated intravascular coagulation (DIC), although cultures were not performed.

Organ system

Table 3 provides causes of mortality by organ system and median age of death in descending order of occurrence in animals excluding infants classified as stillborn or FTT. Multisystem conditions, those involving the gastrointestinal (GI) tract, and cases in which an organ system was not determined accounted for three quarters of deaths in animals >7 days of age. There was a temporal relationship to season in both multisystem and GI diseases with 16 of 21 cases or 76.2% occurring April through July.

In three animals dying of complications secondary to traumatic events, the organ system was classified as musculoskeletal. One animal died within minutes of the trauma due to the severity of wounds, a second died of exsanguination due to a lacerated aorta, and the third developed suppurative myositis as a sequela to the wounds.

Etiologic diagnosis

Table 4 presents causes of mortality by etiology in animals >7 days of age. An infectious etiology was not suspected or confirmed in any infant in the perinatal age group but was seen in all other age groups. Eighteen of the 20 deaths attributed to infectious etiologies occurred April through July, emphasizing the seasonal nature of infectious causes of mortality in sifakas in North America.

Bacterial agents were positively identified in 10 animals. In cases in which tissues were cultured postmortem, heavy growth of a single species was obtained, reducing the likelihood of postmortem overgrowth of bacteria unrelated to disease in the live animal. *Listeria monocytogenes* was cultured from two animals with ulcerative, suppurative colitis and suppurative hepatitis and lymphadenitis. *Yersinia enterocolitica* was isolated from an animal with suppurative myocarditis, lymphadenitis, dermatitis, and interstitial pneumonia. *Streptococcus* sp. was cultured from the blood of both animals with suppurative meningoencephalitis and three animals with *Cryptosporidium* that developed fatal septicemia.

Protozoal organisms, either tachyzoites or cysts, were present on histopathology in nine animals. In addition to four animals with *Crypto-*

Table 2. Morphological diagnosis of mortality by age group.

Morphological diagnosis–pathological finding	Total, $n = 56$ (%)	Perinatal, $n = 17$ (%)	Infant, $n = 10$ (%)	Juvenile, $n = 5$ (%)	Adult, $n = 24$ (%)
Stillborn	11 (19.6)	11 (19.6)	—	—	—
Undetermined	7 (12.5)	—	3 (5.4)	1 (1.8)	3 (5.4)
Enteritis-colitis[a] (necrotizing, suppurative, lymphoplasmacytic, villous atrophy, *Cryptosporidium*)	7 (12.5)	—	2 (3.6)	3 (5.4)	2 (3.6)
Failure to thrive[b]	6 (10.7)	5 (8.9)	1 (1.8)	—	—
Systemic protozoal infection (*Acantamoeba* or *Naegerlia*, *Toxoplasma* or *Neospora,* unclassified *amoeba*)	5 (8.9)	—	1 (1.8)	—	4 (7.1)
Multi-organ suppurative necrosis (lymphadenitis, pneumonia, myocarditis, dermatitis, enterotyphlocolitis)	3 (5.4)	—	—	—	3 (5.4)
Pneumonia (interstitial)	2 (3.6)	—	1 (1.8)	—	1 (1.8)
Trauma (exsanguination, multiple bite wounds)	2 (3.6)	1 (1.8)	—	—	1 (1.8)
Neoplasia (adenocarcinoma, insulinoma)	2 (3.6)	—	—	—	2 (3.6)
Meningoencephalitis (suppurative)	2 (3.6)	—	—	1 (1.8)	1 (1.8)
Multi-organ acute cellular necrosis	2 (3.6)	—	1 (1.8)	—	1 (1.8)
Renal interstitial fibrosis	1 (1.8)	—	—	—	1 (1.8)
Acute segmental intestinal necrosis	1 (1.8)	—	—	—	1 (1.8)
Bone marrow hypoplasia (pancellular)	1 (1.8)	—	—	—	1 (1.8)
Chronic hepatitis (end-stage liver)	1 (1.8)	—	—	—	1 (1.8)
Amyloidosis (systemic)	1 (1.8)	—	—	—	1 (1.8)
Myositis (suppurative)	1 (1.8)	—	1 (1.8)	—	—
Acute vasculitis (necrotizing)	1 (1.8)	—	—	—	1 (1.8)

[a] Cases in which *Cryptosporidium* organisms noted on histopathology were confined to the intestines are included in the enteritis-colitis category.
[b] Specific cause not identified.

sporidium, five animals had organisms consistent with *Acanthamoeba, Naegleria, Toxoplasmosis,* or *Neospora*. In one animal the protozoal species was identified by PCR as *Acanthamoeba*. In the remaining cases of systemic infection, the organisms were classified based on morphological structure on histopathology and further testing to identify the specific genera was not performed.

Table 3. Causes of mortality by organ system.[a]

Organ system	Total $n = 39$ (%)	Median age of death (range)[b]
Multisystem	12 (30.8)	6.0 (0.1–20.6)
Gastrointestinal	11 (28.2)	2.3 (0.3–30.6)
Undetermined	6 (15.4)	0.8 (0.2–21.7)
Musculoskeletal	3 (7.7)	0.1 (0–2.2)
Cardiopulmonary	2 (5.1)	4.3 (0.1–8.4)
Urogenital	2 (5.1)	19.5 (10.3–28.5)
Nervous system	2 (5.1)	2.9 (1.4–4.4)
Hematopoietic	1 (2.6)	15.8

[a] Excludes infants diagnosed as stillborn or failure to thrive.
[b] Age given in years.

Excluding *Cryptosporidium* in which organisms were localized in the intestinal tract, protozoal organisms were present in multiple tissues including the liver, lungs, brain, spleen, pericardium, mediastinal lymph nodes, small intestine, and/or skeletal muscle. The ages of animals succumbing to protozoal infections ranged from 24 days to 17.9 yr.

No viral agents were conclusively identified as a cause of mortality in any sifaka in this study although a viral etiology was suspected in both cases of acute, multi-organ cellular necrosis based on the distribution of necrosis in tissues and vessels on histopathology.

Neoplasia was identified as the primary cause of death in two animals and was localized to the GI system in both instances. A 30.6-yr-old

Table 4. Causes of mortality by etiology.[a,b]

Etiology	Confirmation method	*n*
Infectious-bacterial		(13)
Listeria monocytogenes	Blood culture antemortem, liver culture postmortem	2
Streptococcus, nonhemolytic	Blood culture antemortem	2
Escherichia coli	Blood culture antemortem	2
Bacteria, species not identified	Histopathology	2
Burkholderia cepacia	Blood culture antemortem	1
Steptococcus, α-hemolytic	Blood culture antemortem	1
Klebsiella pneumoniae	Culture of lung postmortem	1
Yersinia enterocolitica	Culture of lymph node aspirate postmortem	1
Clostridium difficile	Toxoid A and B in feces, antemortem	1
Infectious-protozoal		(9)
Cryptosporidium sp.	Histopathology of intestines	4
Acanthamoeba or *Naegleria*	Histopathology of multiple tissues, PCR	3
Ameba-unidentified	Histopathology of brain	1
Toxoplasmosis or *Neospora*	Histopathology of multiple tissues	1
Trauma	Clinical history, gross postmortem exam	3
Neoplasia	Histopathology	2
Degenerative-inflammatory	Histopathology	2
Undetermined		14

[a] Excludes stillborn infants and failure to thrive.
[b] Some animals had multiple agents identified.

individual had two different forms of neoplasia—adenocarcinoma of the duodenum and insulinoma in the pancreas—and an 11.5-yr-old had a mucinous adenocarcinoma of the small intestine.

DISCUSSION

Almost a third of the mortality in this study occurred in infants within the first week of life. Such high mortality in the first days of life has a dramatic impact on the breeding program of these endangered primates in human care and developing a better understanding of factors contributing to obstetrical complications and perinatal death is important for maintaining healthy breeding populations. Nearly two-thirds (64.7%) of deaths in the perinatal group were due to stillbirths. Because necropsies were not performed on seven of the stillborn infants, the ability to draw conclusions about possible causes is limited. Nonetheless, the high number of males stillborn compared with females was unexpected.

Male mortality bias resulting in poor obstetrical outcomes and stillbirth has been well documented in humans and has also been reported in nonhuman primates including vervet monkeys (*Chlorocebus pygerythrus*) and cynomolgus macaques (*Macaca fascicularis*).[1,15,20,27] The causes are likely multifactorial and are not fully understood. Male human fetuses have higher rates of antenatal complications and stillbirths including a higher incidence of preterm labor, failure of labor progression, umbilical cord complications, macrosomia (excessive birth weight in a neonate), small gestational age, and abruptio placentae than females.[1,20] Abruptio placentae has also been documented at higher rates in male cynomolgus macaques while macrosomia was a contributing factor in higher rates of males being stillborn in vervet monkeys.[15,27] Al-Qaraghouli et al suggests there is likely a "sex specific maternal-placental-fetal interaction" that accounts for the higher rates of adverse obstetrical outcomes for male infants.[1] Further study is needed to determine whether fetal sex mortality bias in Coquerel's sifakas is a consistent finding in human care and whether perinatal male mortality rates are higher in other lemur species.

The median age of mortality for all animals in the study was quite low at 1.3 yr of age. The high number of infants lost in the perinatal period substantially lowers the median age of mortality. If infants dying before 30 days of age are excluded, the median age increases to 3.4 yr; however, this number does not take into consideration aged individuals still alive in the collection. Zehr et al calculated the median age of death of Coquerel's sifaka >30 days of age housed at all North American institutions at 10.3 yr using mathematical models that accounted for animals that are still alive.[32] Hence, calculating median ages of mortality using only data from animals that die during a given time frame does not reflect

the current state of a population. Despite this discrepancy, it is evident that Coquerel's sifakas surviving past the first 30 days of life have an increased probability of survival, further underlining the importance of better understanding the causes of mortality in early infancy.

Infections contributed to mortality in a substantial number of animals in this study and occurred predominately during the warmer months of the year. One possible explanation is that infectious agents and disease vectors including insects, ticks, and parasites tend to thrive in warm, humid environmental conditions that are common in the southeastern United States where the facility is located. Supporting this hypothesis is that 18 of 20 deaths (90%) attributed to infectious origins occurred April through July, including four of five systemic protozoal infections, five of six cases of enteritis, colitis, or typhlocolitis, and all cases of bacterial meningoencephalitis, pneumonia, and systemic *Listeriosis.*

The number of infections attributed to protozoa or amoeba is remarkable given the small sample size of the study and suggests that Coquerel's sifakas may be particularly susceptible to infection with such agents. Systemic infections due to protozoa of the genus *Acanthamoeba, Naegleria, Toxoplasmosis,* or *Neospora* were present in five animals and *Cryptosporidium* was identified in the intestines of four other individuals. *Acanthamoeba* and *Naegleria* are free-living amoebas that are ubiquitous in nature and are opportunistic pathogens. They are easily isolated from streams, sewage, polluted water, soils, and dust worldwide.[18,30] During the years infections with these organisms occurred, sifakas were housed in outdoor enclosures with mulch substrates. Organic substrates in combination with poor drainage may have created ideal conditions for the organisms to thrive. After new animal housing was built that eliminated the use of soil and mulch substrates and improved drainage, no further cases of systemic amoebic infections occurred, stressing the importance of proper enclosure design in the prevention of such diseases. Amebic meningoencephalitis, while generally rare in most nonhuman primate colonies, has nonetheless been reported in a range of nonhuman primate species including a variety of apes, monkeys, and black and white ruffed lemurs (*Varecia vargiegata)*.[2,3,9,19,24,31]

While toxoplasmosis is known to be fatal to lemurs of multiple species including ring-tailed lemurs and Verreaux's sifakas, toxoplasmosis was not a major contributor to mortality in this study.[4,8,13,28] This may indicate that preventative measures instituted at the DLC in the early 1990s aimed at reducing exposure to cysts in the environment and on food were effective.

Cryptosporidium organisms were identified in the intestines of four animals. While sifakas may not succumb to *Cryptosporidium* specifically, debilitation and intestinal inflammation may predispose animals to systemic infections or other disorders that are ultimately fatal. Indeed, three animals in this study diagnosed with *Cryptosporidium* developed septicemia and died within 2 wk of being diagnosed with the organism.

Gastrointestinal disease and multisystem disorders were the most commonly affected organ systems in sifakas dying after 7 days of age. The frequency of GI disease seen in Coquerel's sifakas may be due to the difficulty feeding these specialized hind-gut fermenting primates appropriate diets in human care settings.[14] This is consistent with reports in other primate species in human care. In a review of mortality of captive baboons, mortality due to disorders of the GI tract accounted for 21.2% of death in all ages after undetermined cases were excluded.[7] A recent review summarizing morbidity and mortality in great apes found that reports concerning the GI tract were third in frequency and made up 12% of all reports exceeded only by those involving the cardiovascular system and multisystem disorders.[3] Common enteric pathogens such as *Salmonella, Shigella*, and *Campylobacter* were not identified in any animal in this study although one animal with systemic *Yersinia enterocolitica* had both intestinal and systemic lesions.

The high incidence of multisystem disease is not surprising given that many disease conditions affect multiple systems as the disease progresses. Animals receiving veterinary care to prolong life often have advanced disease at the time of their death. This is similar to reports in other nonhuman primates including great apes and baboons (*Papio* spp.).[7,29]

Surprisingly, primary cardiac disease was not identified in any animal. The three animals dying of conditions related to the cardiovascular system died due to pneumonia or systemic infections involving the cardiovascular system. This contrasts with great apes in which cardiovascular disease is a common cause of death in aged animals.[17,29] The fact that cardiac disease was not identified even as an incidental finding in any of the older animals in this study suggests that cardiac disease is not the concern for Coquerel's

sifakas that it is for great apes in a human care setting.

There were several limitations with the study, including a relatively small sample size and the fact that mortality information was drawn from a single institution. Although the DLC holds the largest number of Coquerel's sifakas in human care, incorporating data from all institutions holding Coquerel's sifakas would add statistical power and may have identified causes of mortality not seen in the DLC population.[11] Records from the early years of the study often lacked detail and medical terminology varied considerably depending on the pathologist who performed the initial review, making it difficult to consistently categorize and compare cases with similar clinical histories and lesions. In addition, because mortality was categorized by primary cause and organ system, it was not possible to fully evaluate the impact of multifactorial comorbidities. Similarly, the lack of specific findings on postmortem exam and histopathology in infants dying during the perinatal period limited the ability to draw meaningful conclusions regarding the causes of mortality during this critical time period. Lastly, specific causes of mortality could not be determined for 14 animals, including seven infants for which postmortem exams were not performed. This accounts for 25% of cases and constitutes a large proportion of the study population. Hence, conclusions drawn from this study are preliminary and additional information is needed to gain a more complete understanding of causes of mortality in Coquerel's sifakas in human care.

CONCLUSIONS

High rates of infant mortality during birth and the early neonatal period negatively impact the long-term viability of the population and breeding program in North America for this endangered lemur. Research aimed at better understanding the causes of stillbirths and early neonatal mortality is critical for improving infant survival as are studies aimed at verifying whether male infants consistently have poorer obstetrical outcomes in the larger population.

Bacterial and protozoal infections were the most common cause of death in animals >7 days of age. Thus, sifakas may be more susceptible than other primate species to common pathogens encountered in human care settings.

Mortality in Coquerel's sifakas at the Duke Lemur Center was seasonal with higher rates occurring April through July, which correlated strongly with mortality associated with infectious etiologies. Collecting mortality information from facilities housing Coquerel's sifakas in regions with different environmental conditions would help identify factors contributing to mortality in human care settings.

This was a preliminary study and it is unknown whether trends identified are representative of those seen in other institutions or the larger North American population. Additional research into the impact of husbandry, diet, and environment on health and disease is desperately needed to ensure optimal health and reproduction in this unique primate.

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