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REVIEW

# A review of coccidiosis in South American camelids

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## Abstract
Camelids (llamas, alpacas, vicuñas, guanacos) are important for the economy of South America and *Eimeria* infections are important as cause of mortality in camelids. Of the five most prevalent species of *Eimeria* in South American camelids, *Eimeria macusaniensis*, *Eimeria lamae*, *Eimeria alpacae*, *Eimeria punoensis*, and *Eimeria ivitaensis, E. macusaniensis* is considered the most pathogenic. There is considerable confusion concerning the endogenous developmental stages of *Eimeria* spp. in camelids. Many papers on camelid coccidiosis were published in local Peruvian journals, not easily accessible to wider audience. The objective of the present paper is to summarize information on history, validity of *Eimeria* species, life cycle, pathogenicity, prevalence, epidemiology, diagnosis, and control of coccidiosis in camelids.

**Keywords** Vicuñas (*Lama vicugna*) · Llamas (*Lama glama*) · Alpaca (*Lama pacos*) · Guanacos (*Lama guanicoe*) · *Eimeria* species

## Introduction

The South American camelids consist of four species—llamas (*Lama glama*), alpacas (*Lama pacos*), guanacos (*Lama guanicoe*), and vicuñas (*Lama vicugna*); their generic nomenclature is controversial. I have used the genus *Lama* for all four species. Traditionally, they are distributed at high altitudes (3600–5400 m) in South America where they are source of meat, hide, fiber, transport and their feces are used for fuel and fertilizer (Díaz et al. 2016). In many countries, such as the USA, they are reared for recreation and the commercial product is a live animal. Coccidiosis is an important cause of mortality in llamas and alpacas. There are many uncertainties concerning the life cycle of *Eimeria* species in camelids and early literature from Peru is in local journals, not easily accessible. The object of this review is to summarize information on coccidiosis in camelids.

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## Species of *Eimeria* in camelids

There are five common species of *Eimeria* in South American camelids (Table 1). They are morphologically so different in size and shape that species can be identified without the need of sporulation (Fig. 1). Of these, *E. macusaniensis* and *E. ivitaensis* are one of the largest among species of *Eimeria* in general (Levine 1973).

The sporulation time differs among these *Eimeria* species. *Eimeria macusaniensis* oocysts take longer time to sporulate, perhaps related to the thickness of the oocyst wall. Temperature of incubation can also affect sporulation; *E. macusaniensis* oocysts sporulated in 9 days at 30 °C, in 21 days at 18–25 °C but oocysts did not sporulate at 6–7 °C (Rohbeck 2006).

## History

*Eimeria macusaniensis* oocysts are morphologically and biologically distinctive, resembling watermelon seed or a cut avocado; its oocysts are up to 107 μm long, have a very thick wall, and prepatent period is > 30 days. Examination of coprolites and llama mummies dating about 10,000 years (Halocene period) in Patagonia, Argentina found *E. macusaniensis* and *E. ivitaensis* oocysts (Martinson et al. 2003; Fugassa et al. 2008, 2010; Velázquez et al. 2014; Taglioretti et al. 2014,

**Table 1** Common species of *Eimeria* in South American camelids

| Character | *E. macusaniensis* | *E. lamae* | *E. alpacae* | *E. punoensis* | *E. ivitaensis* |
|---|---|---|---|---|---|
| Oocyst shape | Ovoid, piriform | Ellipsoidal, ovoid | Ellipsoidal, ovoid | Ellipsoidal, ovoid | Ellipsoidal |
| Size[a] | 81–107 × 61–80<br>**100–110 × 77–84**[b] | 30–40 × 21–30<br>**35–38 × 26–30** | 22–26 × 18–21<br>**24–27 × 22–24** | 17–22 × 14–18 | 83.5–98.6 × 49.3–59.1 |
| Mean | 93.6 × 67.4<br>**106.6 × 80.5** | 35.6 × 24.5<br>**36.7 × 28. 9** | 24.1 × 19.6<br>**25.8 × 22.9** | 19.9 × 16.4 | 88.8 × 51.8 |
| Wall thickness | 8.3–11.4 | 1.4–1.8 | 1.2–1.6 | 0.8–1.1 | 4.0–4.5 |
| Micropylar cap | 2–5 high, 9–14 wide | 1.5–2.2 high, 8.8–11.4 wide | 0.7–1.3 high, 4.4–7.5 wide | 0.4–0.8 high, 3.5–5.5 wide | Absent[c] |
| Sporocyst shape | Elongate | Elongate, ovoid | | Elongate, ovoid | Elongate |
| Size range | 33–40 × 16–20<br>**44–48 × 20–23** | 13–16 × 8–10<br>**17–20 × 9–12** | 10–13 × 7–8<br>**10–12 × 7–9** | 8–11 × 5–7 | 32.6–40.8 × 11.9–13.6 |
| Mean | 36.3 × 18.3<br>**45.2 × 22.6** | 15.2 × 8.5<br>**18.6 × 10.7** | 11.0 × 6.8<br>**11.3 × 7.8** | 9.2 × 6.1 | 35.4 × 13.1 |
| Stieda body | Faint | Present | Faint | Faint | Not described |
| Original host | *Lama pacos* | *Lama pacos* | *Lama pacos* | *Lama pacos* | *Lama pacos* |
| Reference | Guerrero et al. (1971) | Guerrero (1967a, b) | Guerrero (1967a, b) | Guerrero (1967a, b) | Leguía and Casas (1998) |

[a] The measurements are in μm. Guerrero (1967a, b) measured 50 or more oocysts and sporocysts; the number of specimens measured by Leguia and Casas (1998) and Schrey et al. (1991) was not stated

[b] Figures in bold are from oocysts in *Lama glama* (Schrey et al. 1991)

[c] Absent in original description of Leguía and Casas (1998) but present in some oocysts (see Fig. 1)

2015); shape and sizes of these oocysts were remarkably preserved (Fugassa et al. 2008). Similar findings are reported for coprolites from Chile dating to Pre-Inca Hispanic Contact Period (de Souza et al. 2018).

Although coccidia have been recognized for more than two centuries (Levine 1973), little attention was paid to coccidia in camelids. Yakimoff (1934) in Leningrad, Russia first reported *Eimeria* infection in feces of one of the five llama fecal samples sent to him by Professor Iwanoff; nothing was said who collected samples and the locality. Yakimoff (1934) named the parasite*, Eimeria peruviana*, n.sp. The oocysts were 27.9–37.5 × 18–22 μm with 10.5–15.0 × 7.5 μm sporocysts, some oocysts had a micropyle but others did not. No other details were given. It appears that there was a mix up with other feces sent by Iwanoff because *E. peruviana* has not been found subsequently. Because there are no archived specimens, this question cannot be resolved retrospectively. I consider it *nomen nudum/species enquirende*.

As per Guerrero (1967a), *Eimeria* infections were reported in alpacas in Peru by Arnao (1951), Chávez (1959), Chávez and Guerrero (1960), Chávez (1965), and Vásquez et al. (1965); these papers were published in local journals or in conference proceedings and are no longer available because the files have been discarded (personal communication from Dr. Guillermo Leguía to me, January 10, 2018). As per Guerrero (1967a), Arnao (1951) first reported *Eimeria* sp. in feces of alpacas, and Chávez (1959) found *Eimeria* oocysts in 17% of 2109 fecal samples. Chávez and Guerrero (1960) found *Eimeria* in the intestine of an alpaca and in feces of 14% of 300 alpacas (Chávez and Guerrero 1960). Vásquez et al. (1965) reported *Eimeria* oocysts in the intestine of llamas in Peru.

Carlos Antonio Guerrero (1967a, b) from Peru came to the University of Illinois, Urbana, Illinois, USA, and under the supervision of Professor Norman D. Levine, formally described and named the three species of *Eimeria, E. alpacae, E. punoensis*, and *E. lamae*. The samples had been collected from the rectum of 12 alpacas from an alpaca farm in Peru, mixed with 2.5% potassium dichromate or 10% formalin and sent to USA. Apparently, most oocysts had sporulated during transit thus, in the original published paper there was no description of unsporulated oocysts (Guerrero 1967b). However, unsporulated oocysts of *E. alpacae* and *E. punoensis* (but not *E. lamae*) were described in his thesis (Guerrero 1967a). After completing his graduate studies, Guerrero returned to Peru and together with Hernandez and Alva reported severe coccidiosis in a 5-month-old alpaca; the alpaca was in poor nutritional condition and had died a day before necropsy (Guerrero et al. 1967). It had mixed infection of *E. lamae*, *E. alpacae*, *E. punoensis*, and an unnamed *Eimeria* species. They also reported schizonts, gamonts, and oocysts in histological sections; the stages found were arbitrarily assigned to four species of *Eimeria*. Four years later, Guerrero et al. (1971) described and named *Eimeria macusaniensis*.

Guerrero et al. (1970b) also first reported on experimental infection of *E. lamae* in alpaca. Two alpacas were fed 100 oocysts (6 months-old alpaca #1) or 100,000 oocysts (4 months old alpaca #2). Both excreted *E. lamae* oocysts 10 days (alpaca #2) or 16 days (alpaca #1) later. Alpaca #2 developed diarrhea and died day 15 post inoculation (p.i.). Small schizonts (not

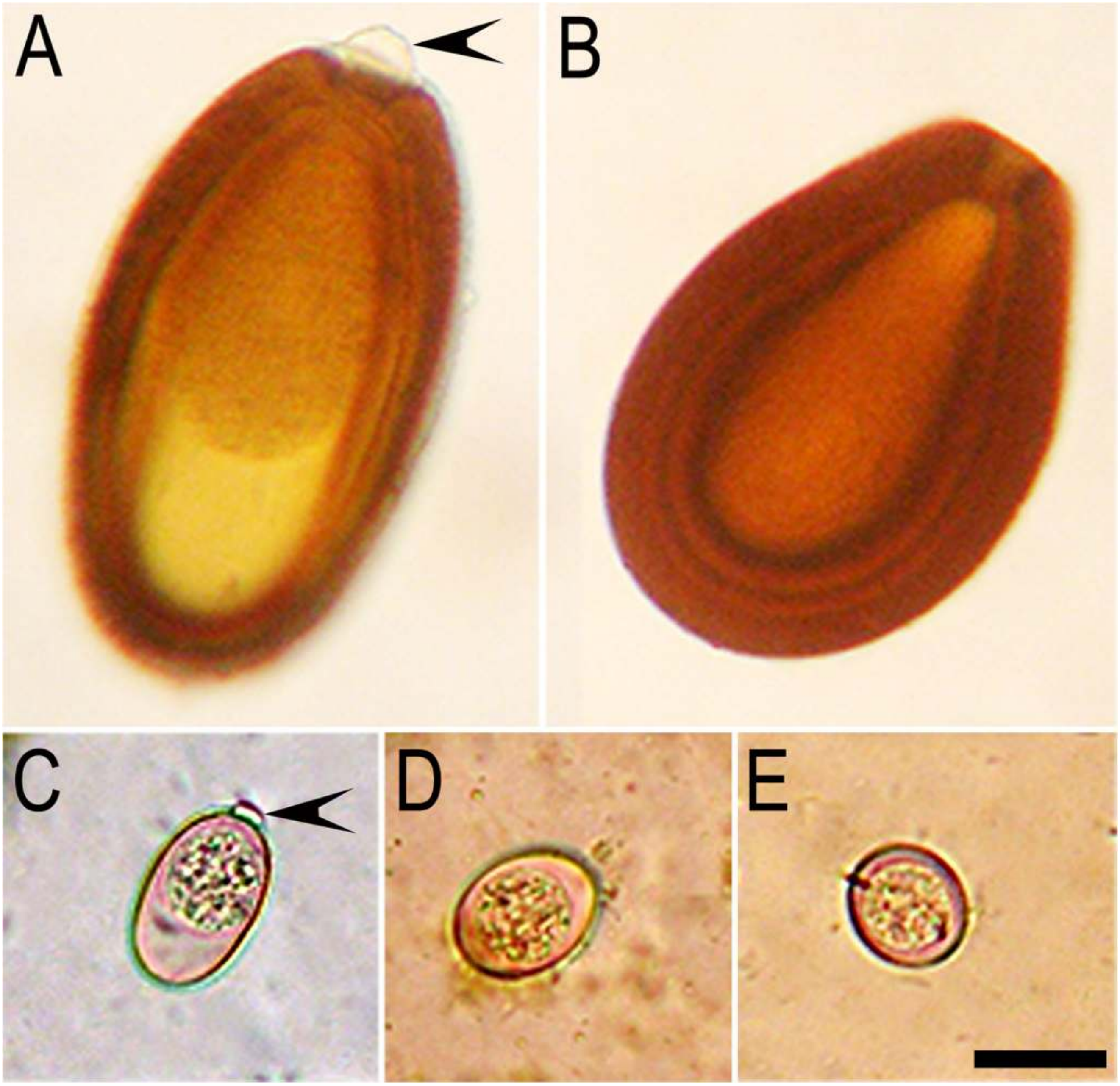


**Fig. 1** Unsporulated oocysts of five common species of *Eimeria* in South American camelids. Unstained. Courtesy of Dr. M. M. Cafrune. **A** *E. ivitaensis*. **B** *E. macusaniensis*. **C** *E. lamae*. **D** *E. alpace*. **E** *E. punoensis*. Note micropylar caps (arrowheads). The scale bar = 20 μm and applies to all parts

illustrated) were found in the duodenum, and numerous gamonts and oocysts were found throughout the small intestine at necropsy.

Three decades later, Leguia and Casas (1998) described the fifth species of *Eimeria, E. ivitaensis* (Table 1).

## Prevalence of *Eimeria* species oocysts in feces

Prevalence data in llamas (Table 2), alpacas (Table 3), guanacos (Table 4) and vicuñas (Table 5) indicate these camelids are commonly infected with *Eimeria* species. The data from North America and South America camelids are grouped together but the patterns of infections might be different in these continents. In general, *E. lamae* was the most prevalent and *E. ivitaensis* was the least prevalent. Infections were most common in nursing animals. Up to 90% of cria under 2 months of age were found infected (Guerrero et al. 1971). It is noteworthy, that despite excretion of as many as 411,600 oocysts per gram of feces (opg), all vicuñas were asymptomatic (Cafrune et al. 2014).

**Table 2** Prevalence of *Eimeria* in Llama (*Lama glama*)

| Country, region | No. tested | No. positive (%) | *Eimeria species* | Remarks | Reference |
|---|---|---|---|---|---|
| Argentina | | | | | Cafrune et al. (2009) |
| Jujuy | 478 | 233 (48.7) | *E. macusaniensis* in all, mixed with *E. ivitaensis* in 2 | 1 llama with mixed *E. macusaniensis* and *E. ivitaensis* had diarrhea | |
| Salta | 48 | 17 (35.4) | *E. macusaniensis* in 17 | | |
| Catamarca | 100 | 65 (65) | *E. macusaniensis* in all, mixed with *E. ivitaensis* in 2 | | |
| Switzerland | 293 from 38 farms | (68) | *E. macusaniensis* | Only herd prevalence stated. | Hertzberg and Kohler (2006) |
| USA | | | | | Rickard and Bishop (1988) |
| Oregon | 189 adults | 69 (37) | *E. alpacae* (27%), *E. macusaniensis* (1%) *E. punoensis* (17%), *E. lamae* (9%), | 1 species in 58%, 2 species in 38%, 3 species in 4% in adults. | |
| | 50 crias | 30 (60) | *E. alpacae* (52%), *E. macusaniensis* 0, *E. punoensis* (40%), *E. lamae* (32%), | In crias, 47% contained 2 species, 30% had 3 species, 23 % had 1 species. All animals were healthy. | |
| 10 states | 301 | 36 (12) | *E. macusaniensis* | <1 year 19 of 86 (22.1%), > 1 year 17 of 200 (8.5%) | Jarvinen (1999) |
| Colorado and Wyoming | 121 Colorado | 76 (62.8) | *E. alpacae* 75, *E. macusaniensis* 0, *E. lamae* 1 | 4 herds surveyed | Schrey et al. (1991) |
| | 23 Wyoming | 15 (65.2) | *E. alpacae* 5, *E. macusaniensis* 2, *E. lamae* 8, | | |

**Table 3** Prevalence of *Eimeria* in alpacas (*Lama pacos*)

| Country-region | No. tested | No. positive (%) | *Eimeria* species % | Remarks | Reference |
|---|---|---|---|---|---|
| Japan Kanto | 53 | 42 (79.2) | *E. lamae* 1.9 *E. macusaniensis* 7.5 *E. punoensis* and/or *E alpacae* 69.8 | 53 of 390 alpacas from 1 farm tested | Hyuga and Matsumoto (2016) |
| New Zealand | 460 | 15 (3.2) | *E. macusaniensis* | 5 farms were surveyed | Rawdon et al. (2006) |
| Peru Cuzco | 160 | 67 (58.1) | *E. lamae* 60.4, *E. punoesis* 30.0, *E. alpace* 45.6 *E. macusaniensis* 50.4 | 90% of 2 months-old alpacas were positive with an oocyst burden of 1016 oocysts per gram of feces | Guerrero et al. (1970a) |
| Southern Peru | 316 | 145 (46.2) | *E. macusaniensis* 56.5 | 22 herds surveyed | Cordero Ramirez et al. (2011) |
| Puno | 478 | 418 (87.5) | *E. lamae* 15.6, *E. punoesis* 20.0, *E. alpace* 16.9 *E. macusaniensis* 25 *E. ivitaensis* 6.2 | < 90 days old healthy cria, infection with multiple species was common | Rodríguez et al. (2012) |
| Puno | 350 | 224 (64.3) | *E. lamae* 91, *E. macusaniensis* 35, *E. punoensis* 78, *E. alpacae* 87, *E. ivitaensis* 13 | Unweaned alpacas 2 from 23 herds | Díaz et al. (2016) |
| Switzerland | 72 | Not stated | *E. macusaniensis* | Present in 68% of farms, no individual animal data | Hertzberg and Kohler (2006) |
| UK | Not stated | Not stated | *E. ivitaensis* | Present in 2 herds. Zinc sulfate sp. gr. 1.36 used for flotation | Twomey et al. (2010) |
| USA-10 states | 115 | 8 (7.0) | *E. macusaniensis* | | Jarvinen (1999) |
| Maryland | 61 | 14 (26.2) | *E. alpacae* in 7, *E. punoensis* in 5, mixed in 2 | Two farms. Cesium chlorite sp.gr. 1.4 used for flotation | Trout et al. (2008) |

**Table 4** Prevalence of *Eimeria* in guanaco (*Lama guanicoe*)

| Country-region | No. tested | No. positive (%) | *Eimeria* species | Remarks | Reference |
|---|---|---|---|---|---|
| Argentina Salta | 4 | 1 (25.0) | *E. macusaniensis* | Semi captive | Cafrune et al. (2009) |
| Mendoza, San Juan | 35 | Not stated | *E. macusaniensis, Eimeria* sp. | Wild guanaco surveyed. Only published as abstract | Borghi et al. (2004) |
| Patagonia | 12 | 10 (80.3) | *E. macusaniensis* in 9, *Eimeria* spp. in 10 | Mortality due to starvation in wild population. Feces were from animals necropsied | Beldomenico et al. (2003) |
| Chile Magallanes | 15 | 6 (40.0) | *E. macusaniensis* | Semi captive | Correa et al. (2012) |
| Peru 9 districts | 132 | 43 (33.3) | *E. punoensis* 21.2%, *E. alpacae* 13.6%, *E. lamae* 4.5%, *E. macusaniensis* 15.9% | Wild population | Castillo et al. (2008) |
| USA-10 states | 27 | 2 (7.4) | *E. macusaniensis* | | Jarvinen (1999) |

## Clinical infections

Little is known of camelid coccidiosis in the wild (Leguía 1991; Mamani Paredes et al. 2009; Cafrune et al. 2014). However, *Eimeria* infections can be pathogenic in camelids dependent on age, concurrent infections, environmental conditions, stress of captivity and transportation, and nutrition in general (Díaz et al. 2016). Some of these factors have been investigated.

Reports of clinical coccidiosis in camelids are summarized in Table 6. Except for a report of coccidiosis in a captive guanaco from the USA (Hodgin et al. 1984), all clinical reports were in llamas and alpacas.

Among reports summarized in Table 6, a comprehensive investigation of causes of mortality was performed on 15 llamas, and 34 alpacas submitted to the Oregon Diagnostic Laboratory, Oregon State University hospital during 2002–2006 (Cebra et al. 2007). The following is the most important information from this paper:

(a) *E. macusaniensis* infections were diagnosed in 49 camelids 3 weeks to 18 years old. The clinical signs were weight loss, lethargy, and diarrhea. Of these, 10 llamas and 9 alpacas were examined at necropsy.

(b) Feces or intestinal contents of 42 camelids were examined by flotation; *E. macusaniensis* oocysts were not found in 17 but *E. macusaniensis*-associated enteritis was confirmed histologically. The other *Eimeria* oocysts identified were: *E. lamae* and *E. alpacae*.

**Table 5** Prevalence of *Eimeria* in vicuñas (*Lama vicugna*)

| Country-region | No. tested | No. positive (%) | *Eimeria* species | Remarks | Reference |
|---|---|---|---|---|---|
| Argentina Jujuy | 81 juveniles<br>154 adults | 81 (100.0)<br>143 (92.8) | *E. punoensis* (100%), *E. alpacae* (85.1%), *E. lamae* (48.1%), *E. macusaniensis* (82.7%), and *E. ivitaensis.* (3.7%)<br>*E. punoensis* (89.6%), *E. alpacae* (66.8%), *E. lamae* (27.2%), *E. macusaniensis* (15.5%), and *E. ivitaensis.* (1.2%) | Born and raised at an experimental station. Prevalences were higher in May versus in November, 2011. All were asymptomatic. Mixed infections were common | Cafrune et al. (2014) |
| Bolivia Apolobamba | 25 adults<br>7 juveniles | 22 (88)<br>7 (100) | *E. alpacae* 88%, *E. puneonsis* 80.0%, *E. lamae* 12%, and *E. macusaniensis* 8%<br>*E. alpacae* 100%, *E. puneonsis* 100%, *E. lamae* 42.9%, and *E. macusaniensis* 14.3% | Wild population | Beltrán-Saavedra et al. (2011) |
| Peru Pampa Galeras | 39 Adults | 15 (41.0) | *E. punoensis*/*E. lamae* | Wild population, opg (<48) | Bouts et al. (2003) |

**Table 6** Summary of reports of clinical *Eimeria* infections in South American camelids

| Country | Host | *Eimeria* spp. | Main findings | Reference |
|---|---|---|---|---|
| Australia | Alpaca | *E. macusaniensis* | A 10-year-old alpaca died suddenly without prior clinical signs. Severe, necrotic enteritis with massive parasitization of small intestine. No evidence for clostridial or other toxins. Oocysts in feces were 80–82 × 50–52 μm and sporocysts were 34 × 18 μm | Lenghaus et al. (2004) |
| Germany | Llama | *E. macusaniensis* | Thirteen of 16 one to three year-old llamas developed diarrhea and died within 2 months after a long distance travel from northern Germany to Bavaria. Enteritis associated with *E. macusaniensis* was found in three llamas necropsied. | Hänichen et al. (1994) |
| New Zealand | Alpaca | *E. macusaniensis* | A 10-year-old female alpaca diagnosed with histologically confirmed ulcerative coccidial enteritis affecting ileum and rare parasitism in duodenum. Endogenous stages (schizonts, gamonts, oocysts) were present in histological sections. Oocysts were seen antemortem and the alpaca had been treated with an unspecified anticoccidial drug | Rawdon et al. (2006) |
| Peru | | | | |
| Puno | Alpaca | *Eimeria* spp. | Heavy coccidiosis in a 5-month-old alpaca. Schizonts and gamonts of *E. lamae* and *E. ivitaensis* found in histological sections | Guerrero et al. (1967) |
| Southern sierra | Alpacas | *E. macusaniensis* | Twelve 25–35-day-old alpacas that died suddenly ($n = 4$) and 8 with diarrhea were necropsied and studied histologically. Macroscopic and microscopic lesions were seen in jejunum and ileum. Necrosis, fusion and blunting of villi were associated with schizonts and gamonts, and oocysts | Rosadio and Ameghino (1994) |
| IVITA, La Raya, Cusco | Alpaca | *E. macusaniensis, E. lamae, E punoensis; E. ivitaensis* | Investigations of causes of diarrhea in 48 newborn alpacas found entrotoxemia in 30, collibacillosis in 7, and *Eimeria* in 11; *E. macusaniensis* in 4, *E. macusaniensis* and *E. punoensis* in 7, and *E. lamae* in 4. Authors mentioned finding *E. macusaniensis* stages in small intestine, cecum, and colon. Intracellular stages of *E. ivitaensis* were reported in crypts of jejunum and ileum for the first time | Palacios et al. (2005) |
| Marang-ani, Cusco | Alpaca | *E. macusaniensis; E. ivitaensis* | Sudden onset of diarrhea, emaciation, and death in seven 4–5-month-old alpacas from one herd. Enteritis was the main finding. *E. macusaniensis* stages were found in jejunum, ileum, cecum, and ascending colon whereas *E. ivitaensis* stages were restricted to jejunum and ileum. Schizonts, gamonts, and oocysts were identified for both species; schizonts of *E. ivitaensis* caused more damage than schizonts of *E. macusaniensis.* Microgamonts of both species appeared similar but gamonts were different; the wall forming bodies of *E. ivitaensis* were small and basophilic whereas those of *E. macusaniensis* were large and eosinophilic | Palacios et al. (2004,2006) |
| Arequip-a, Puno, Cusco | Alpaca | *E. macusaniensis* | Histological evaluation of 108 cases of *Clostridium*-induced enterotoxemia in 2–8-week-old alpacas revealed (a). *E. macusaniensis* in 33 (30.5%). (b) massive infection in 3 of 31 alpacas less than 2 weeks old; 2 of these were only 10 days old. (c) infections observed even in well managed herd. (d) severe lesions in jejunum and ileum in crypts | Rosadio et al. (2010) |
| Silli, Cusco | Alpaca | *Eimeria* sp. | Causes of diarrhea in an outbreak involving 50 1- to 5-week-old alpacas were investigated. 80% had *Eimeria* spp. infections; alone in 19, and in combinations with other agents in 21 alpacas. Illustrations from a 21-day-old alpacas show heavy coccidial infections, different from *E. macusaniensis* | Rojas et al. (2016) |
| UK | Alpaca | Oocysts of *E. macusaniensis*, *E lamae*, and *E. alpace* in feces | The index case, a 16-month-old alpaca, was found dead with a short period of restlessness. Histologic examination revealed acute, necrotic enteritis with *Clostridium perfringens* toxemia. Lesions associated *E. macusaniensis* stages. | Schock et al. (2007) |

**Table 6** (continued)

| Country | Host | *Eimeria* spp. | Main findings | Reference |
|---|---|---|---|---|
| | | | 54 additional cases of coccidiosis recorded; 40 confirmed, 9 suggestive, and 5 incidental. Most cases were in adults. Of the 26 with established diagnosis, 10 were associated with *E. macusaniensis,* 7 with *E. punoensis,* 1 with *E. alpacae,* 1 with *E. lamae;* mixed *Eimeria* spp. in 7. | |
| USA | | | | |
| Michigan | Guanaco | *E. macusaniensis* | 3-month-old female guanaco from Detroit Zoological Park died of acute illness with leptospiral nephritis and hepatitis. The animal had abdominal pain. At necropsy a 60 cm section of jejunum was congested. Histologically, it had subacute enteritis with gamonts and oocysts of *E. macusaniensis*; feces were not available for oocyst identification. | Hodgin et al. (1984) |
| Wyoming | Llama | *E. macusaniensis* | 3-year-old female llama died after short illness associated with enterotoxemia. Asexual and sexual stages reported in ileum. *E. macusaniensis* oocysts found in feces | Schrey et al. (1991) |
| Missouri | Alpaca or llama not distinguished | *Eimeria* sp. | 2 alpacas with weight loss and hypoproteinemia. Both had been vaccinated against *C. perfrigens*. First alpaca 10-year-old diagnosed antemortem with *E. macusaniensis* based on jejunal biopsy died 5 days despite of treatment with sulfadimethoxine. The alpaca had chronic weight loss. Coccidial stages found in jejunum and ileum. The second animal died after diarrheal episode. Necropsy revealed *Eimeria* stages in jejunum and ileum but no oocysts in feces | Chigerwe et al. (2007) |
| New York | Alpaca | *E. macusaniensis* | Two-year-old female alpaca with abdominal pain, hypoproteinemia. Ultrasound examination revealed thickened loop of small intestine with collapsed lumen. Histological examination of biopsied small intestinal area revealed severe parasitism with *E. macusaniensis* stages. The alpaca recovered after sulfadimethoxine treatment. Oocysts of two species of *Eimeria* were present in feces, predominantly *E. punoensis* | Johnson et al. (2009) |
| Oregon | 15 llamas, 34 alpacas | *E. macusaniensis* | See text for details | Cebra et al. (2007) |
| Illinois | 1 llama | *E. macusaniensis* | Weight loss. Gametogony described in detail | Dubey (2018) |

**Table 7** Pathogens identified in feces of neonatal alpacas with diarrhea

| Source | No. | Age (days) | Year | Percent of samples | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *E. coli* | Corona virus | *Cryptosporidium* | *Giardia* | Rota virus | *Eimeria* | |
| Oregon, USA[a] | 45 | 10–210 | 1999–2002 | NS | 42 | 9 | 18 | 2 | 13 | Cebra et al. (2003) |
| Ohio, USA[b] | 59 | 4–120 | 1999–2004 | 0 | 6.9 | 25.9 | 32.8 | 0 | 12.1 | Whitehead and Anderson (2006) |
| Puno, Peru[c] | 48 | newborn | 2002–2003 | 77[f] | NS[e] | 4.1 | NS | NS | 31.4[g] | Palacios et al. (2005) |
| Cusco, Peru[d] | 50 | 7–35 | January–February, 2010 | 34 | 40 | 20 | NS | 32 | 80 | Rojas et al. (2016) |

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[e] NS = not stated

[f] Of the 37 cases of bacterial infection, 30 were due to enterotoxemia

[g] 4 cases of *Eimeria macusaniensis* and enterotoxemia, 7 mixed infection with *E. macusaniensis* and *E. punoensis*, and 4 cases due to *E. lamae*

**Table 8** Experimental infections of camelids with *Eimeria* species

| Host species (no.) | *Eimeria* species | No. of oocysts | Prepatent period in days | Reference |
|---|---|---|---|---|
| Llama (4) | *E. alpacae*-25%, *E. punoensis* 75%-both from **llama** | 10,000–2 llamas, 50,000, 2 llamas | *E. alpacae*-16-18, *E. punoensis*-10 | Foreyt and Lagerquist (1992) |
| Llama (4) | *E. macusaniensis*-**Guanaco** | 500–5000 | 36–41 | Jarvinen (2008) |
| (3) | *E. macusaniensis*-**Alpaca** | 1000 | 33, 34 | |
| Llama (6) | *E. macusaniensis*-**Llama and alpaca** | 20,000–100,000 | 32–36 | Rohbeck (2006) |
| Alpaca (4) | *E. macusaniensis*-**Alpaca and llama** | 20,000 | 31 or 35 | Cebra et al. (2012) |

[a] Source of infection is in bold

(c) Multiple sections of intestines were available for histological examination in 29 of 34 cases of *E. macusaniensis*. *Eimeria macusaniensis* lesions were most severe in jejunum and ileum. Meronts, macro and micro-gamonts, and oocysts were reported in histological sections; the identification of species was based on large size of wall-forming bodies in developing gamonts and oocysts found.

(d) Early gamonts, but no mature gamonts, were detected in 13 camelids in whose feces oocysts were not demonstrable.

(e) Most interesting information was obtained from outbreaks of coccidiosis in 15 camelids on four farms. One outbreak occurred in a group of alpacas, 20 days after being introduced to new premises that had been vacant for 6 months. Six additional alpacas became ill within


**Fig. 2** Proliferative enteritis in ileum of an alpaca. This animal had concurrent *Salmonella* infection. Courtesy of Prof. Robert Bildfell, Oregon State University, Corvallis, USA


**Fig. 3** Small intestine of a 7 years-old pregnant alpaca that died with a severe hemorrhagic enteritis attributed to *Eimeria macusaniensis*. Courtesy of Dr. Gerald E. Duhamel, Cornell University, Ithaca, New York

13 days; four of these died and were necropsied. *Eimeria macusaniensis* was diagnosed histologically. *Eimeria macusaniensis* oocysts were detected in feces of five alpacas 37 days after move to the new premises; these alpacas had diarrhea. The resident alpacas moved to the same pasture at the same time remained healthy.

(f) This investigation concluded that *E. macusaniensis*-associated coccidiosis is common cause of illness in camelids of all ages in Oregon.

## Concurrent infections and other causes of mortality

During a retrospective study of 3766 alpacas that had died between 1998 and 2000 in three production centers in Peru,

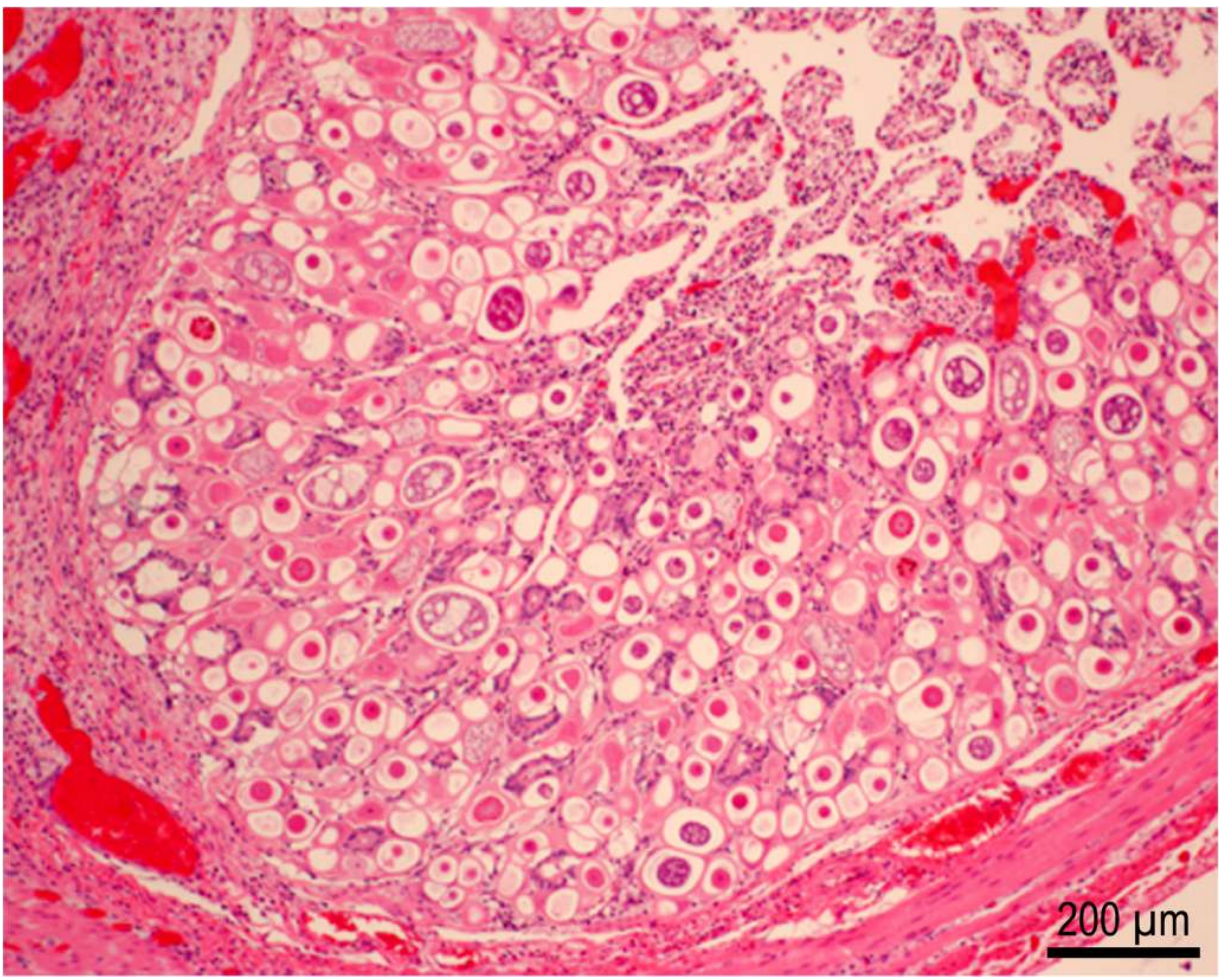


**Fig. 4** Massive infection of *Eimeria macusaniensis* small intestine of a 7-month-old alpaca from Indiana, USA (OSU case 07-1238). This animal also had histologically verified enterotoxemia in other sections of small intestine. The gamonts are immature and there are no oocysts. Hematoxylin and eosin stain. Courtesy of Prof. Michael Oglesbee, The Ohio State University, Columbus, USA

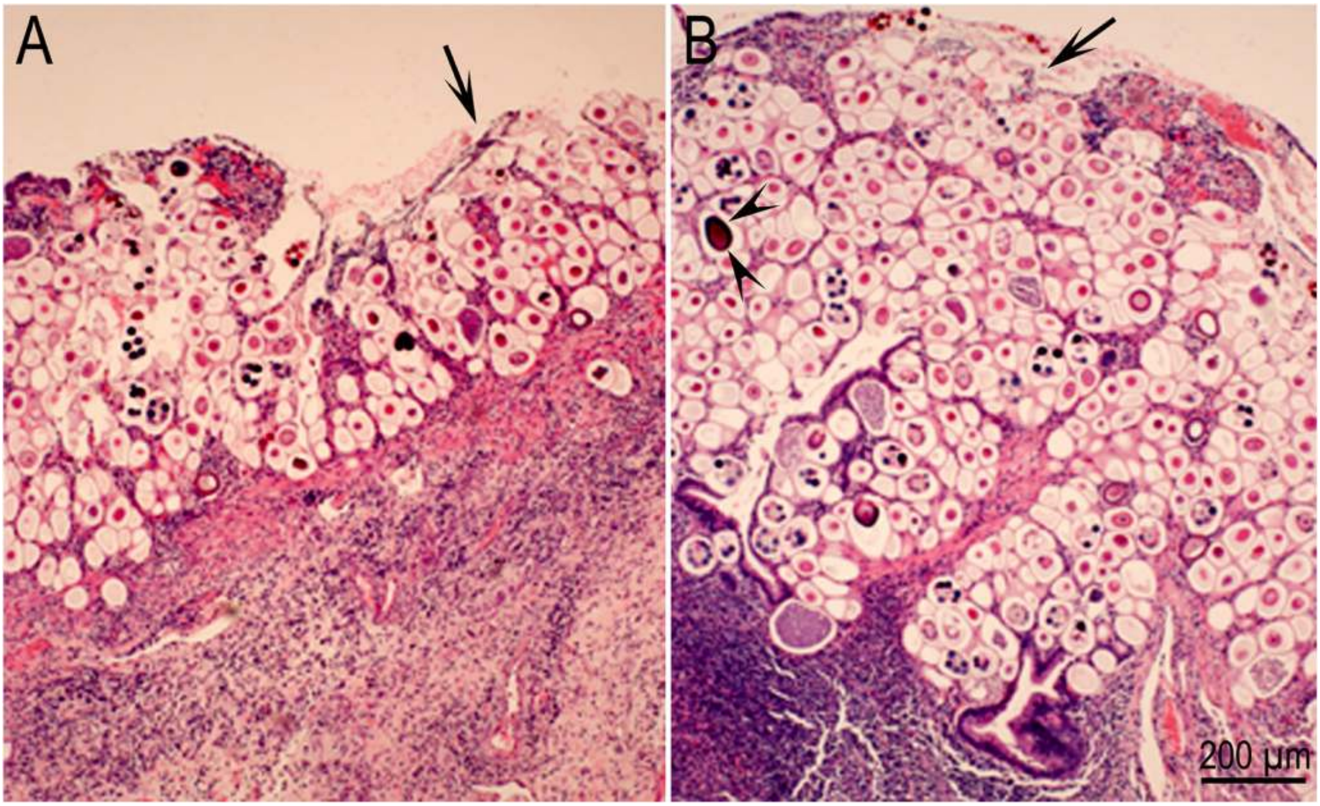


**Fig. 5** Biopsy of jejunum from a 2-year-old female alpaca with severe enteritis associated with *Eimeria macusaniensis* (Johnson et al. 2009). Hematoxylin and eosin stain. Courtesy of Dr. Gerald E. Duhamel, Cornell University, Ithaca, New York. Arrows point to loss of surface villar mucosal structures. **A** The mucosa is replaced with gamonts and oocysts. Note severe inflammation within the underlying submucosa. **B** Higher magnification shows ulcerative enteritis. Note an oocyst (arrowheads)

parasitic disease accounted for 3.0%; 51.7% of deaths were attributed to infectious causes (Mamani Paredes et al. 2009). Among the parasitic diseases, coccidiosis was found in 25.4%. Thus, coccidiosis was recognized as cause of mortality only in few alpacas. However, a critical evaluation of etiology was lacking in this investigation.

Neonatal diarrhea is a common problem in raising livestock and diagnosis is problematic because of multiple etiology. Examples of pathogens found in cases of neonatal diarrhea in camelids are shown in Table 7. Despite all referred pathogens that can cause diarrhea, their relative importance is difficult to determine. An unusually severe outbreak of diarrhea was investigated in an alpaca herd in Silli, Cusco, Peru (Table 7). Of 50 affected alpacas, 6 died and 44 were euthanized; all were examined at necropsy (Rojas et al. 2016). Histologically, 44 of 50 alpacas had enteritis and 80% had *Eimeria* sp. infections. It is uncertain whether the diagnosis of *Eimeria* infections was based solely on fecal testing or histology. One illustration (Fig. 3 of Rojas et al. 2016) of small intestine shows heavy coccidiosis with small-sized *Eimeria* but there was no mention of species involved or description of parasitic stages (my attempts to obtain more information about endogenous stages were unsuccessful).

In an enquiry of causes of neonatal deaths in young alpacas (2–4 months old) from three alpaca centers in Peru, histological sections of intestine of 108 alpacas considered to have died from enterotoxemia were examined for evidence of *E. macusaniensis* infection. Only sections of intestines from grossly visible lesions were examined. Most ($n = 103$) sections were from the ileum with only five from jejunum. *Eimeria macusaniensis* developmental stages were detected in 33 alpacas. Of the 31 alpacas with available ages, three were 2 weeks old; two were only 10 days old (Rosadio et al. 2010). These findings indicate that alpacas can become infected on the day of birth because the minimum prepatent period of any camelid *Eimeria* is 10 days (Table 8).

Coinfection of coccidiosis and enterotoxemia were associated with mortality in newborn alpacas in another report (Palacios et al. 2005, Table 7).

## Stress

Housing in close quarters and poor nutrition are some of the complicating factors in coccidiosis. Stress of transportation and change of ownership/location can

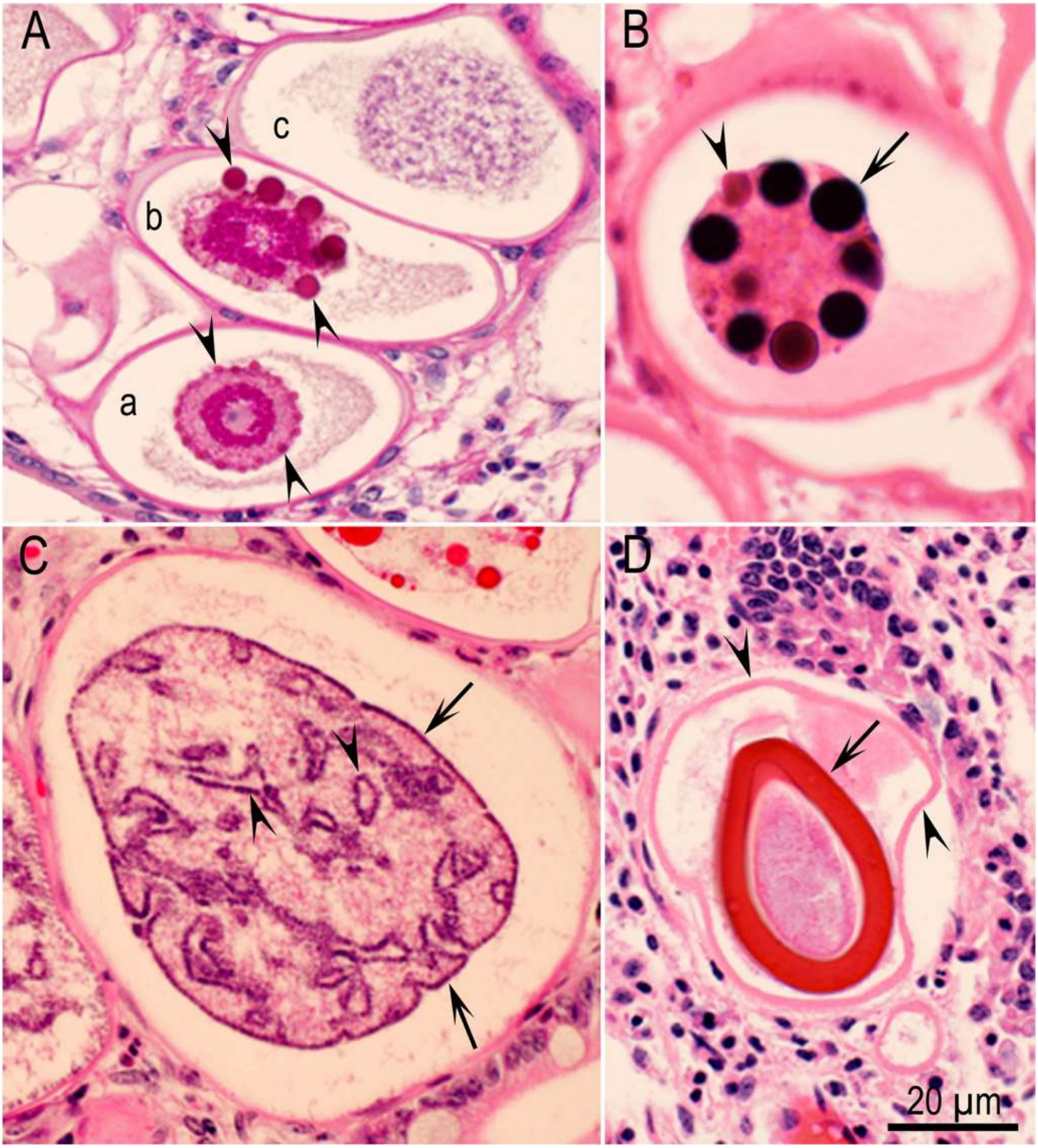


**Fig. 6** Gamonts and oocysts of *Eimeria macusaniensis* in sections of small intestine of llama. **A** Note intracellular gamonts. (a) Early macrogamont with PAS-positive (amylopectin granules) around the central nucleus, and small-sized wall forming bodies (WFB, arrowheads). (b) More advanced macrogamont with WFB (arrowheads). (c) Immature microgamont with many nuclei. PAS-counter stained with hematoxylin. **B** Macrogamont with different sized WFB (arrow, arrowhead). Hematoxylin and eosin stain. **C** Microgamont with numerous nuclei arranged at the periphery (arrows) or centrally (arrowheads). **D** An intracellular oocyst. Note, sporont filling the interior of the oocyst, thick oocyst wall (arrow), truncated anterior micropylar end, and thick parasitophorous vacuole (arrowheads). Hematoxylin and eosin stain

predispose camelids to coccidiosis. Shows, sales, and movement for breeding, and the management in the new farm can cause stress. In one instance, 30 llamas developed clinical coccidiosis after being transported to a new farm (Cebra et al. 2007). Adult alpacas have developed fatal coccidiosis within 5 weeks after transportation to a new farm (Chigerwe et al. 2007; Johnson et al. 2009).

## Diagnosis

### Antemortem

Lethargy, diarrhea, abdominal distention, anorexia, weight loss, constipation, and colic have been reported in camelids with uncomplicated coccidiosis (Costarella and Anderson 1999; Cebra et al. 2007; Johnson et al. 2009). Coccidiosis should be suspected with these signs in camelids. Additionally, several camelids suffering from coccidiosis died suddenly (Rosadio and Ameghino 1994; Lenghaus et al. 2004; Palacios et al. 2006; Schock et al. 2007). It should be noted that diarrhea is an inconsistent finding, especially in adult camelids (Cebra et al. 2014).

### Fecal examination

The detection of oocysts in feces can help diagnosis. Although most coccidian oocysts float in sugar or salt solutions with specific gravity (sp. gr.) of 1.28, *E. macusaniensis* oocysts are large and heavy and do not float well in these solutions (Cebra and Stang 2008). Solutions of sp. gr. > 1.28 are recommended for floatation of this *Eimeria* species. Super saturated sugar solution (sp. gr. 1.33, Johnson et al. 2009), saturated zinc sulfate solution (sp.gr. 1.36, Twomey et al. 2010), Cesium chlorite solution (sp. gr. 1.4, Trout et al. 2008) or mixed salt solutions (zinc chloride 105 g, NaCl 20 g, water to 100 ml, sp. gr. 1.59, Cafrune et al. 2009) are some examples of flotation solutions. The sedimentation methods used for trematode ova are as effective as the flotation method (Rohbeck 2006). The number of oocysts detected does not correlate with clinical signs (Foreyt and Lagerquist 1992; Costarella and Anderson 1999; Beldomenico et al. 2003; Cebra et al. 2007; Jarvinen, 2008; Foreyt and Lagerquist 1992; Rohbeck 2006; Cafrune et al. 2014). Some cases of coccidiosis may be missed because of the development of clinical signs before oocysts are excreted in feces (prepatent phase). To alleviate this problem, Cebra et al. (2012) developed a polymerase chain reaction (PCR) test for *E. macusaniensis* and *E. lamae* diagnosis. In experimentally infected alpacas, oocyst DNA was detectible up to 7 days before oocyst detection in feces. The internal transcribed primers (ITS) were species-specific without cross detection of *E. macusaniensis* and *E. lamae.* Finding *Eimeria* oocyst DNA, 7 days before prepatent period is intriguing.

### Biopsy and ultrasound examination

Ultrasound examination results revealing local distention and increased thickness of small intestine, particularly of ileum, may provide suggestive diagnosis (Costarella and Anderson 1999; Cebra et al. 2007; Johnson et al. 2009). Smears made from biopsied material can reveal the parasitic stages (Cebra et al. 2007). However, histological examination is needed to evaluate lesions (Cebra et al. 2007; Chigerwe et al. 2007; Johnson et al. 2009).

### Other laboratory testing results

Hypoproteinemia and hypoalbuminemia are the most consistent finding (Cebra et al. 2007). Hyponatremia is also relatively common, and a rare finding in camelids without some form of enteritis.

### Post mortem diagnosis

Gross lesions are most common in ileum, although any region of small intestine, cecum and colon may be affected (Rosadio and Ameghino 1994; Palacios et al. 2006; Cebra et al. 2007; Johnson et al. 2009). Mucosal thickening, congestion, plaques and severe hemorrhagic enteritis may be seen in primary lesions (Figs. 2 and 3). Secondary bacterial infection can lead to severe necrotic enteritis (Cebra et al. 2007; Schock et al. 2007; Johnson et al. 2009; Rosadio et al. 2010). The bowel may also appear grossly normal, even with severe infection.

Microscopically, there is hyperplasia, non-suppurative enteritis, depending on concurrent infections (Figs. 4 and 5). Blunting, fusion, and necrosis of villi, particularly at the tips have been reported (Rosadio and Ameghino 1994; Johnson et al. 2009). Although developmental stages of camelid *Eimeria* occur in the mucosal epithelium and lamina propria, occasionally *Eimeria* and associated changes have been noted in the tunica muscularis mucosae (Johnson et al. 2009).

The detection of developing stages of coccidia can establish diagnosis of coccidiosis (Fig. 6). As stated earlier, of the five most prevalent species of *Eimeria* in camelids, *E. macusaniensis* has been most commonly identified in lesions. Its oocysts are distinctive, and it has large-sized gamonts (Figs. 4, 5, and 6). Its schizont stage is unknown (Dubey 2018). In few cases, *E. ivitaensis* has been associated with clinical coccidiosis in alpacas in Peru (Palacios et al. 2006) and the United States (Cebra et al. 2014; Cebra 2015).

*Eimeria lamae* is another pathogenic species. It is reported to develop in surface epithelium versus in crypts parasitized by *E. macusianiensis* and *E. ivitaensis* (Guerrero et al. 1967); I have not found description of endogenous stages.

## Experimental infections

In addition to experimental infections of two alpacas in Peru by Guerrero et al. (1970a) already discussed, results of four other experiments are summarized in Table 8. Main observations from experiments in Table 8 are:

(a) Minimum prepatent periods were: 31 days for *E. macusaniensis,* 16 days for *E. lamae*, and 10 days for *E. punoensis* (Table 8).
(b) Inoculated camelids generally remained asymptomatic despite excreting as many as 10,305 opg; peak oocyst excretion for *E. lamae*, and *E. punoensis* was during the second week of inoculation (Foreyt and Lagerquist 1992). However, 2 of 5 llama crias fed 20,000 *E. macusaniensis* oocysts had pulpy or watery or bloody diarrhea 3–10 or 9–16 days p.i. (Rohbeck 2006).
(c) *Eimeria macusaniensis* was cross transmissible between guanaco, alpaca, and llama.
(d) *Eimeria macusaniensis* oocysts survived for 84 months, the longest period of any known *Eimeria* species (Jarvinen 2008).
(e) *Eimeria macusaniensis* was mildly immunogenic because llamas excreted *E. macusaniensis* oocysts after reinoculation; in challenged llamas the prepatent period was longer (37–40 days versus 32–36 days after primary infection), patency was shorter (39–43 days versus 20–23 days after challenge) and fewer oocysts were excreted after challenge) (Rohbeck 2006).

## Treatment

There are no anti-coccidial drugs approved specifically for camelids. Benzene acetonitrile compounds (ponazuril, diclazuril, toltrazuril), sulfonamides, and amprolium have been used to treat or prevent coccidiosis in camelids (Cebra et al. 2007, 2014; Ballweber 2009; Thomas and Morgan 2013; Franz et al. 2015).

Efficacy of various drugs for treating clinical coccidiosis is unknown. None of anticoccidials have any measurable effect on late stages of gamonts and oocysts that have been commonly related with clinical coccidiosis associated with *E. macusaniensis* and *E. ivitaensis*.

Treatment for coccidiosis included amprolium hydrochloride (10 mg/kg) in a 1.5% solution orally daily up to 15 days, or sulfadimethoxine (110 mg/kg) orally daily for 10 days, and supportive therapy. However, some camelids died despite this therapy and had confirmed coccidiosis histologically (Cebra et al. 2007). In one instance, an entire herd of 30 alpacas that developed coccidiosis 20 days after introduction to a new farm was treated with amprolium hydrochloride, two died and four were euthanized. Two of the four that died had histologically confirmed coccidiosis (Cebra et al. 2007).

The benzene acetonitrile compounds in general have low toxicity. They are used extensively to treat coccidiosis in camelids in countries where they are readily available in a convenient treatment form.

Prophylactic treatment should be considered during winter when outbreaks of coccidiosis are common. Decoquinate may be added to feed at 0.5 mg/kg/day for 4 weeks (Cebra et al. 2014).

In summary, therapeutic treatment for coccidiosis in South camelids needs validation.

## Conclusion and prospective

It is evident from the above review that coccidiosis can be serious in captive camelids. Under free range/wild environment in South America, camelids can excrete numerous oocysts in feces without showing clinical signs. The pathogenesis of fatal coccidiosis is not fully understood, because even adult camelids can die suddenly, and animals can develop clinical signs long before oocysts are detected in feces. Whether there are differences in biology of *Eimeria* species in camelids in North America and South America needs further investigation. Among the five valid species of South American camelid *Eimeria*, *E. macusaniensis* appears to be most pathogenic. Only gamonts and oocysts have been confirmed in histological sections of intestines in cases associated with *E. macusaniensis.* There is need to investigate unknown endogenous stages of camelid coccidia. It appears that heavy parasitization of *E. macusaniensis* in crypts of ileum predisposes camelids to other enteric pathogens, particularly *Clostridium perfrigens* toxemia. There are no anticoccidial drugs specifically approved for use in camelids.

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