A review of coccidiosis in South American camelids

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Received: 15 March 2018 / Accepted: 23 April 2018 / Published online: 26 May 2018

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.

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 (Holocene 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,
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 *nommen 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

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

| Character         | *E. macusaniensis* | *E. lamae* | *E. alpacae* | *E. punoensis* | *E. i vitae nis* |
|-------------------|--------------------|------------|--------------|----------------|-----------------|
| Oocyst shape      | Ovoid, piriform    | Ellipsoidal, ovoid | Ellipsoidal, ovoid | Ellipsoidal, ovoid | Ellipsoidal      |
| Size              | 81–107 × 61–80     | 30–40 × 21–30 | 22–26 × 18–21 | 17–22 × 14–18  | 83.5–98.6 × 49.3–59.1 |
| Mean              | 93.6 × 67.4        | 35.6 × 24.5 | 24.1 × 19.6  | 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 |
| Sporocyst shape   | Elongate           | Elongate, ovoid | Elongate, ovoid | Elongate       |                 |
| Size range        | 33–40 × 16–20      | 13–16 × 8–10 | 10–13 × 7–8 | 8–11 × 5–7     | 32.6–40.8 × 11.9–13.6 |
| Mean              | 36.3 × 18.3        | 15.2 × 8.5  | 11.0 × 6.8  | 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) |

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**References**

1. Fugassa et al. 2008.  
2. Figures in bold are from oocysts in *Lama glama* (Schrey et al. 1991).  
3. Absent in original description of *Leguía glama* (Schrey et al. 1991).
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       |            |                  |                   |         |           |
| 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 | Cafrune et al. (2009) |
| 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 farms  | (68)             | *E. macusaniensis* | Only herd prevalence stated. | Hertzberg and Kohler (2006) |
| USA             |            |                  |                   |         |           |
| Oregon          | 189 adults | 69 (37)          | *E. alpacae* (27%), *E. macusaniensis* (1%), *E. punoensis* (17%), *E. lamae* (9%), *E. alpacae* (52%), *E. macusaniensis* 0, *E. punoensis* (40%), *E. lamae* (32%), | 1 species in 58%, 2 species in 38%, 3 species in 4% in adults. | Rickard and Bishop (1998) |
| Catamarca       | 100        | 65 (65)          | *E. macusaniensis* in all, mixed with *E. ivitaensis* in 2 | In crias, 47% contained 2 species, 30% had 3 species, 23% had 1 species. All animals were healthy. | Guerrero et al. (1999) |
| Switzerland     | 293 from 38 farms | (68)          | *E. macusaniensis* | Only herd prevalence stated. | Hertzberg and Kohler (2006) |
| USA             |            |                  |                   |         |           |
| Oregon          | 189 adults | 69 (37)          | *E. alpacae* (27%), *E. macusaniensis* (1%), *E. punoensis* (17%), *E. lamae* (9%), *E. alpacae* (52%), *E. macusaniensis* 0, *E. punoensis* (40%), *E. lamae* (32%), | 1 species in 58%, 2 species in 38%, 3 species in 4% in adults. | Rickard and Bishop (1998) |
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| Switzerland     | 293 from 38 farms | (68)          | *E. macusaniensis* | Only herd prevalence stated. | Hertzberg and Kohler (2006) |

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

| Country-region | No. tested | No. positive (%) | *Eimeria* species % | Remarks | Reference |
|----------------|------------|------------------|---------------------|---------|-----------|
| Japan          |            |                  | *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    |            |                  | *E. macusaniensis* | 5 farms were surveyed | Rawdon et al. (2006) |
| Peru           |            |                  | *E. macusaniensis* | 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  |            |                  | *E. macusaniensis* | 22 herds surveyed | Cordero Ramirez et al. (2011) |
| Puno           |            |                  | *E. macusaniensis* | <90 days old healthy cria, infection with multiple species was common | Rodriguez 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 | Diaz 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* | Two farms. Cesium chlorite sp.gr. 1.4 used for flotation | Jarvinen (1999) |
| Maryland       | 61         | 14 (26.2)         | *E. macusaniensis* | Only herd prevalence stated. | Hertzberg and Kohler (2006) |
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 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          | 15         | 6 (40.0)         | *E. macusaniensis*| Semi captive | Correa et al. (2012) |
| Magallanes     |            |                  |                   |         |           |
| Peru           | 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) |
| 9 districts    |            |                  |                   |         |           |
| USA-10 states  | 27         | 2 (7.4)          | *E. macusaniensis*|         | Jarvinen (1999) |

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

| Country-region | No. tested | No. positive (%) | *Eimeria* species | Remarks | Reference |
|----------------|------------|------------------|-------------------|---------|-----------|
| Argentina      |            |                  |                   |         |           |
| Jujuy          | 81 juveniles, 154 adults | 81 (100.0), 143 (92.8) | *E. punoensis* (100%), *E. alpacae* (85.1%), *E. lamae* (48.1%), *E. macusaniensis* (82.7%), *E. vitataeniis* (3.7%) | Born and raised at an experimental station. Prevalences were higher in May versus November, 2011. All were asymptomatic. Mixed infections were common | Cafrune et al. (2014) |
| Bolivia        | 25 adults, 7 juveniles | 22 (88), 7 (100) | *E. alpacae* 88%, *E. punoensis* 80.0%, *E. lamae* 12%, and *E. macusaniensis* 8% | Wild population | Beltrán-Saavedra et al. (2011) |
| Apolobamba     |            |                  |                   |         |           |
| Peru           | 39 Adults | 15 (41.0)        | *E. punoensis*/*E. lamae* | Wild population, opg (<48) | Bouts et al. (2003) |
| 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      | 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     | 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    | Alpaca    | E. macusaniensis, E. lamae, E. punoensis, E. ivitaensis | Investigations of causes of diarrhea in 48 newborn alpacas found entrotoxemia in 30, colibacillosis 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)             |
| Marangani,   | 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)        |
| Arequipa, 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. Hodgins 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. perfringens*. 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. Cociddial 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. (2003)

Illinois 1 llama  *E. macusaniensis*  Weight loss. Gametogony described in detail. Dubey et al. (2007)

Table 7  Pathogens identified in feces of neonatal alpacas with diarrhea

| Source | No. | Age (days) | Year | Percent of samples | Reference |
|--------|-----|------------|------|--------------------|-----------|
| Oregon, USA  | 45 | 10–210 | 1999–2002 | NS 42 9 | Cebra et al. (2003) |
| Ohio, USA  | 59 | 4–120 | 1999–2004 | 0 6.9 25.9 | Whitehead et al. (2006) |
| Puno, Peru  | 48 | newborn | 2002–2003 | 77 4.1 | Palacios et al. (2005) |
| Cusco, Peru  | 50 | 7–35 | January–February, 2010 | 34 40 20 | Rojas et al. (2016) |

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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*.
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.

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

**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. alpaca* 25%,  | 10,000–2 llamas,  | *E. alpaca* 16–18,      | Foreyt and Lagerquist (1992) |
|                    | *E. punoensis* 75% | 50,000, 2 llamas | *E. punoensis* 10       |           |
| Llama (4)          | *E. macusaniensis* Guanaco | 500–5000 | 36–41 | Jarvinen (2008) |
| Llama (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) |

* 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](https://example.com/fig2.png) Proliferative enteritis in ileum of an alpaca. This animal had concurrent *Salmonella* infection. Courtesy of Prof. Robert Bildfell, Oregon State University, Corvallis, USA
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 a common cause of illness in camels 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,
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
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

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.
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 chloride 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 (Robbeck 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; Robbeck 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. ivitaeensis 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. macusaniensis and E. ivitaeensis (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. ponoensis (Table 8).
(b) Inoculated camelids generally remained asymptomatic despite excreting as many as 10,305 opg; peak oocyst excretion for E. lamae, and E. ponoensis 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 re-inoculation; 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 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 camels to other enteric pathogens, particularly Clostridium perfringens toxemia. There are no anti-coccidial drugs specifically approved for use in camelids.

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 perfringens toxemia. There are no anti-coccidial drugs specifically approved for use in camelids.

Acknowledgements: I would like to thank Drs. R.J. Bildfell, C. Bauer, M. M. Cafrune, C. K. Cebra, A. Daugschies, P. Diaz, G. Leguía, G. A. Perkins, and R. H. Rosadio who supplied specimens and advice. I also thank Camilla Cezar, Fernando Murata, Oliver Kwok, Andressa Ferreira da Silva, and Shiv Kumar Verma in my laboratory for assistance in preparation of this review.

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