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Technical Memorandum

To: Tommy Brooks

Date: December 29, 2014

Subject: Coccidiosis in Goats and Sheep

CSA was asked to research the academic articles on coccidia transmissions from birds to goats in follow-up to testimony provided to the record by McPhillips Farms.

Attached to this memo is a current scientific review of the disease in goats and sheep from 2012 prepared for the academic journal, "Small Ruminant Research". Also attached are article abstracts from research in Brazil, Czechoslovakia, and the United States.

The literature review reveals the following key points:

1. Coccidiosis is a general term for the clinical condition caused by parasitic infection from many different species of protozoa within the genus *Eimeria*. The literature states that the protozoa that infect sheep and goats are, "specific to each host." In other words, the species that infect sheep are spread by and between sheep.

2. The academic research indicates that Coccidia are present in sheep and goat populations throughout the world. Studies in Brazil and Czechoslovakia were found in over 90% of the goats within the study populations. Management and control of the disease is common the world over and is part and parcel to sheep and goat farming.

3. The academic research indicates that kids and lambs are often infected at a young age but not all experience clinical symptoms. Immunity rises rapidly after weaning.

CSA Planning, Ltd.

Jay Harland
Principal

cc. File

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Coccidiosis due to *Eimeria* in sheep and goats, a review☆

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ABSTRACT

Coccidiosis (Eimeriosis *sensu stricto*) of small ruminants is a protozoan infection caused by several species of the genus *Eimeria* which develop in the small and the large intestine, affect young animals in particular and are specific for each host. *Eimeria ovinoidalis* in sheep and *Eimeria ninakohlyakimovae* in goats are the most pathogenic species. Coccidiosis is of great economic importance because of the losses due to clinical disease (diarrhoea) but also because of subclinical infections (poor weight gain in particular). Oocyst excretion is at the maximum around the weaning period and shows a steady decline afterwards due to a strong immunity. Risk factors for high excretion include breeding intensification, high stocking rates in premises, poor hygiene and all causes of stress (physiological, nutritional, etc.). Reliable diagnosis include combined clinical, epidemiological, necropsic and coproscopical approaches. Control is mainly based on hygienic measures between lambing/kidding and weaning periods and on anticoccidial compounds use.

1. Introduction

Coccidiosis (Eimeriosis *sensu stricto*) of small ruminants is a protozoan infection caused by coccidia parasites of the genus *Eimeria* which develop in the small and the large intestine and affect young animals in particular. Several species of *Eimeria* are involved in different ruminant hosts (bovine, ovine, caprine) but there is no cross infection due to the strict host specificity. Coccidiosis is of great economic importance because of the losses due to clinical disease (diarrhoea) and subclinical infections as well (poor weight gain in particular). Another coccidia of uncertain taxonomic status, *Eimeria* (*Globidium*) *gilruthi*, is responsible of incidental infections of the abomasums in sheep and goat (Maratea and Miller, 2007).

Economic importance

In intensive breeding conditions accompanied by a high animal density and high productivity, coccidiosis can become an infection of significant economic importance in small ruminants (Foreyt, 1990). These losses can be linked to reduced production, in the case of moderate infection without clinical signs. In this case the demonstration of the global impact of coccidia on the field is, in general, carried out by comparing the performances of groups of animals treated with preventive coccidiostatic substances over long periods and untreated control groups (Foreyt et al., 1986). This approach is global and takes into account the different effect of infection on digestive physiology (intake, digestive utilisation). For example, in replacement young goats, a prolonged administration of decoquinate for 80 days after weaning increased the weight gain and was linked, afterwards, to an increase in the milk production during the first

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Table 1
Parasitic development and pathogenic effect of caprine coccidia[a] (according to Yvoré et al., 1985).

Species	Peak of excretion	Oocysts per gram of faeces	End of excretion	Symptoms
E. alijevi	12th day	8000	18th day	None
E.ninakohlyakimovae	16th day	200,000	26th day	Diarrhoea, anorexia
E. arloingi	25th day	25,000,000	40th day	Diarrhoea
E. christenseni	28th day	2000	64th day	None

[a]With an infective dose of 100,000 oocysts.

lactation when compared to control (Morand-Fehr et al., 1999). Thus, the majority of these studies shows an impact of coccidial infections although no economic justification is generally given. In fact, the economic profitability of such an approach is rarely taken into consideration and remains to be proved. The economic impact of coccidiosis in small ruminants is not well documented in tropical regions as well but we can suppose that in extensive breeding zones with animals of local origin which present a good level of adaptation, subclinical coccidiosis is probably not of major importance in comparison with other infections.

Clinical coccidiosis, which is more sporadic, also brings economic losses linked to the direct consequences of diarrhoea on the growth of the animals and on possible mortality. No accurate estimation of losses has been made either in intensive or extensive breeding. Chartier (2009) quoted coccidiosis amongst the two main etiologies together with respiratory diseases in necropsic exams from weaned goats. Similarly, Craig (1986) recorded up to 15 p.100 of mortality in Texas Angora young does attributed to coccidiosis. In two studies carried out in East Africa, coccidiosis appears to be a secondary cause of mortality amongst small ruminants in comparison with other parasitic or infectious diseases as pneumonia or helminthosis (Kusiluka et al., 1998; Peeler and Wanyangu, 1998).

2. Pathogens

2.1. Eimeria species and geographical distribution

Sheep or goats harbour their own species of *Eimeria* and there is no cross-infection (Figs. 1 and 2) (McDougald, 1979). For a long time, the species of *Eimeria* in sheep and goats have been considered to be identical on the basis of morphology, which explains the great confusion one can find in the studies published earlier on the different species of *Eimeria* in small ruminants. In temperate areas like western Europe, the most prevalent *Eimeria* species are *Eimeri ovinoidalis* followed by *Eimeri weybridgensis/crandallis* in sheep (Reeg et al., 2005) and *Eimeria ninakohlyakimovae* and *Eimeria arloingi* in goat (Yvoré et al., 1981). In lambs in Germany, faecal samples with 3, 4 or 5 species of *Eimeria* are the most frequent together with a predominance of *E. ovinoidalis* in high oocyst counts samples (Dittmar et al., 2010; Reeg et al., 2005). In semi-arid zones of Gran Canaria (Spain), the most frequent species of *Eimeria* in goats are *E. ninakohlyakimovae*, *E. arloingi* and *Eimeria alijevi* (Ruiz et al., 2006). In mid-western states of USA, the most frequent species of *Eimeria* encountered in goats are *E. arloingi* (98.8%), *Eimeria christenseni* (58.2%), *E. ninakohlyakimovae* and *Eimeria parva* (33.3%) (Lima, 1980).

In dry tropical areas as Senegal, the main species of coccidia are *E. ovinoidalis* (76 p.100) *E. crandallis* (62%), *Eimeria ahsata* (28%) and *E. parva* (25%) in sheep and *E. arloingi* (64%) and *E. ninakohlyakimovae* (56%) in goats (Vercruysse, 1982). Similar results are recorded in Ghana (Nuvor et al., 1998), in Nigeria (Woji et al., 1994), in Kenya (Kanyari, 1993; Maingi and Munyua, 1994) and in Zimbabwe (Chhabra and Pandey, 1991). In dry areas of Sri Lanka, the 3 most prevalent coccidia in goats are *E. ninakohlyakimovae* (31%) *E. alijevi* (29%) and *E. arloingi* (21%) (Faizal and Rajapakse, 2001). Coccidia of small ruminants are thus present worldwide and it seems difficult to say that there is any particular geographical distribution for one or the other species of coccidia.

2.2. Life cycle

The life cycle of *Eimeria* species is homoxenous requiring only one host. It includes an exogenous phase of maturation of the oocyst (sporogony), which occurs outside the host, and a parasitic endogenous phase within the host with an asexual followed by a sexual multiplication (Soulsby, 1982). The proliferative potential in the host is very high since, according to a theoretical calculation, each oocyst ingested could be the origin of 30 million oocysts excreted in faecal matter (Gregory et al., 1987).

The oocysts passed with the faeces are not sporulated. Sporulated oocysts are formed after 2–7 days according to the species of *Eimeria* and the environmental conditions; moisture, oxygen and temperature are particularly important. The sporulated oocysts show a great resistance in the external environment (they can survive several months or even more than a year). However, extreme desiccation, direct exposure to the sun limit the survival of the oocysts and temperatures below −30 °C or above 63 °C are lethal (Foreyt, 1990).

Once ingested by the host, the oocysts undergo a process of excystation. The sporozoites penetrate into an epithelial cell of the small intestine to transform into a schizont. Two asexual multiplication cycles (schizogonies) occur in the small intestine only, or in the small then large intestines, according to the *Eimeria* species. Eventually, the schizozoites penetrate the large intestine epithelial cells (sexual phase or gamogony) that lead to the production of gamontes, gametes and then non sporulated oocysts that are released with the faecal matter (Foreyt, 1990).

For the most important species in goat, *E. ninakohlyakimovae*, the first schizogony takes place in the ileum (10 days post infection – dpi), the second in the crypt cells of the caecum and the colon (12 dpi) and eventually gamogony occurs in large intestine (13 dpi), with a prepatent period of 15 days (Vieira et al., 1997). Similar evolution is described

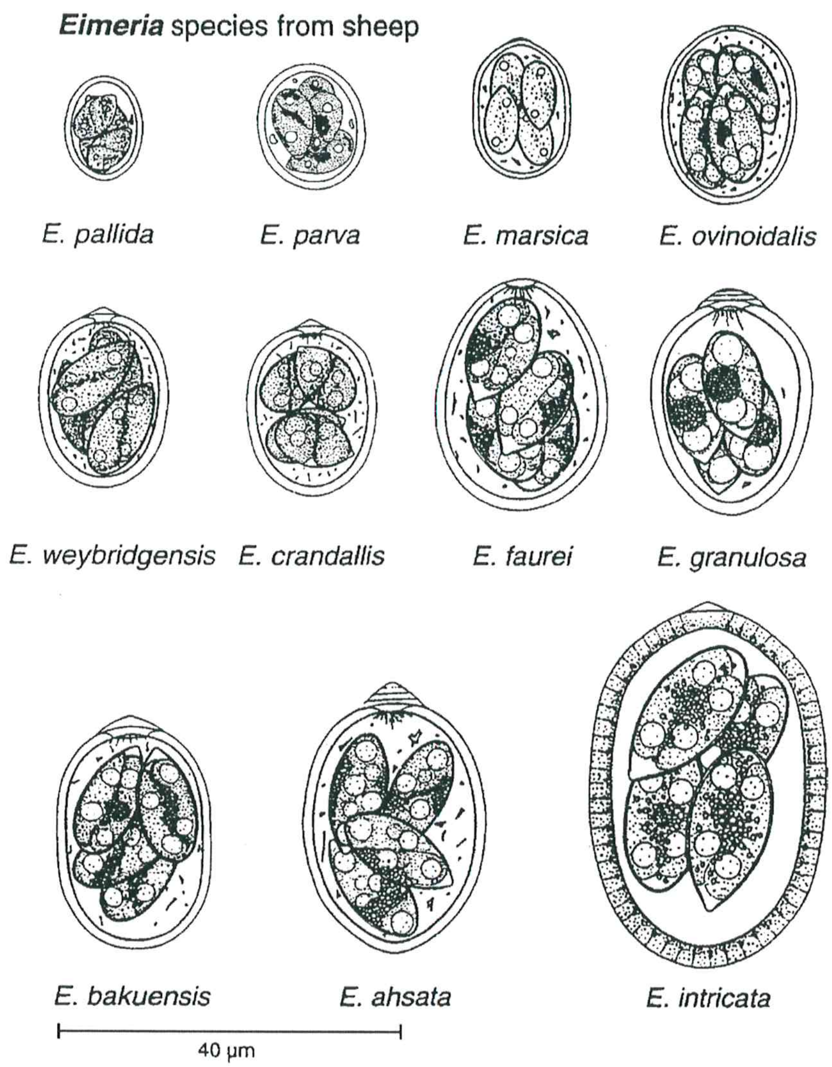

Fig. 1. Sporulated oocysts of the principal species of *Eimeria* in sheep (Eckert et al., 1995).

in sheep with *E. ovinoidalis* (Gregory and Catchpole, 1987). When comparing several *Eimeria* caprine species, the peaks of oocyst excretion range from 12 to 28 dpi (Table 1).

2.3. *Pathogenic effect of coccidia*

2.3.1. *Location of the endogenous development*

In goats, the most pathogenic species which lead to clinical signs are first *E. ninakohlyakimovae* and secondly *E. arloingi* (Table 1) (Koudela and Bokova, 1998; Yvoré et al., 1985). In sheep, *E. ovinoidalis* which develops in the large intestine is considered to be the most pathogenic species followed by *E. crandallis* and possibly *E. ahsata* (Gregory, 1989).

In addition to the pathogenic effect of the parasites, due to the destruction of the epithelial cells of the intestine, the coccidial infection strongly interacts with the digestive microflora. In experimental infections with *E. ovinoidalis* in axenic, gnotoxenic and conventional lambs, it has been shown that the presence of digestive microflora was essential to the development of the parasite pathogenic expression (Gouet et al., 1984). On the other hand, the coccidial infection brings about a massive change to the digestive microflora with a percentage of Gram negative bacteria rising from 16 up to 76 p.100, which is, according to Mohammed et al. (2000) an aggravating or even a determinant factor of the diarrhoea.

2.3.2. *Infective dose*

There is a direct correlation between the quantity of oocysts ingested and the appearance of clinical signs (Fayer, 1989; Gregory et al., 1989b). It has been shown that a daily oral dose of 500,000 oocysts of a mixture of different *Eimeria* species in goats during 5 days, provokes serious clinical disorders with mortality, whereas the ingestion of two times fewer oocysts does not lead to mortality (Yvoré et al., 1980a).

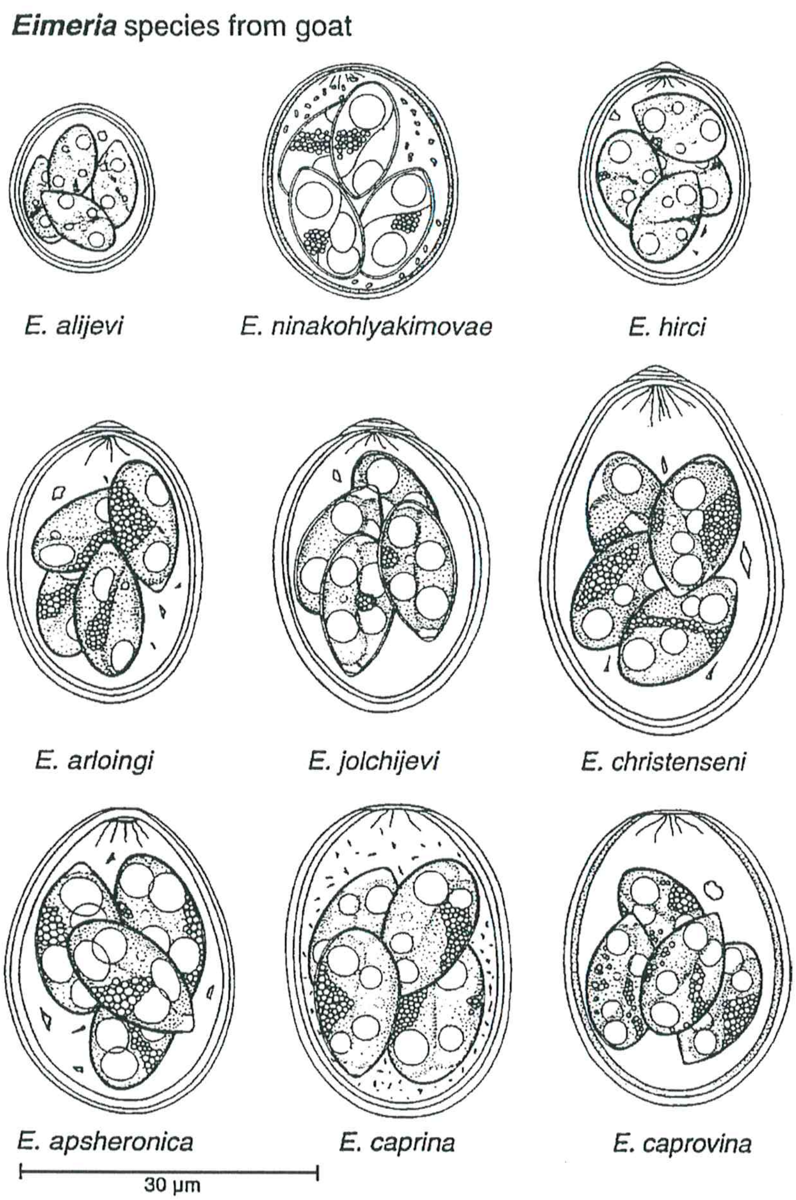

Fig. 2. Sporulated oocysts of the principal species of *Eimeria* in goats (Eckert et al., 1995).

2.3.3. Concomitant infections

The pathogenic effect of coccidia might be aggravated by poly-parasitism affecting the different portions of the digestive tract: the various species of *Eimeria* through the different locations and timing in the reproductive patterns (Craig, 1986) but also gastro-intestinal nematodes (Taylor, 2009), or even other pathogenic agents such as viruses or bacteria (Wright and Coop, 2007).

3. Epidemiology

3.1. Host–parasite relationship and immunity

The excretion of oocysts starts very early at 2–3 weeks of age following ingestion of sporulated oocysts during the first few days of life. Neither *in utero* transmission nor transmission through milk have been demonstrated. There is a progressive increase in the prevalence (the number of animals excreting) and in the intensity of the excretion until a peak is reached around the period of weaning. Afterwards, the intensity of excretion lessens to reach lower values, but not zero, in older animals. Time courses of oocyst excretion suggest an early onset of effective and specific immunity at least for the major *Eimeria* species (prevalence, oocyst counts) while it could be postponed for the minor species (Reeg et al., 2005). A relatively high repeatability in oocyst counts, at least similar to those observed for trichostrongylid eggs counts, was described in natural coccidial infection in sheep and suggest a genetic component in the determination of oocyst ouput (Yvoré et al., 1992).

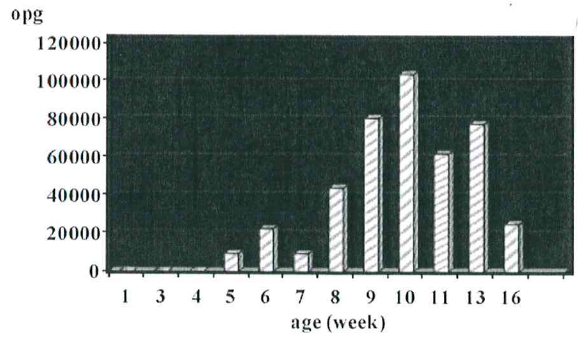

Fig. 3. *Eimeria* oocyst output in kids in France (Yvoré et al., 1981) Opg = oocysts/g faeces.

In goats, numerous authors have reported heavy excretion of oocysts by kids aged between 2 and 4 months (several tens of thousands of oocysts per gram of faeces or OPG), that is to say, a short time after weaning, and a rapid decrease of the excretion of oocysts (to some thousands) with age (Fig. 3) (Agyei et al., 2004; Chartier et al., 1991; Faizal and Rajapakse, 2001; Jalila et al., 1998; Koudela and Bokova, 1998; Ruiz et al., 2006; Yvoré et al., 1981). In older goats (over 7 years), a slight increase in the excretion of oocysts can be noticed, which has been interpreted by certain authors as a relative weakness of the immune system. Similarly, Ruiz et al. (2006) recorded higher oocyst counts in adult goats during the hot season (harsh conditions) on the island of Gran Canaria. Attempt to immunise kids with heterologous infection from sheep origin (*E. ovinoidalis*) was unsucessfull (Chartier et al., 1994).

In sheep, the same excretion pattern was seen in British lambs with no oocyst excretion at birth, a peak excretion around 6 weeks of age followed by a rapid decrease. Adult ewes do not seem to excrete large numbers of oocysts around the time of lambing, as it has been shown for digestive nematode eggs (Gregory et al., 1983). According to Gregory (1989), the dynamics of the oocyst excretion in lambs include a refractory status of lambs to infection at a very early age followed by a period of passive maternal protection afforded by colostrum. However, Reeg et al. (2005) found no indication that maternal antibodies were protective. Lambs already infected by *E. ovinoidalis* and *E. crandallis* are less susceptible to a challenge infection compared with naïve lambs (absence of mortality, less diarrhoea and better growth) (Gregory and Catchpole, 1989). Catchpole et al. (1993) succeeded in correctly immunising lambs with a single inoculation at birth, thus ensuring, during challenge infection at 28 days, a lowering of the mortality rate from 80 to 20 p.100 in comparison with non immunised control animals. This immunisation is even more efficient when it is carried out at a later age of lamb and when the parasitic development has been completed and accompanied by clinical signs. These experimental data are reinforced by observations in the field: clinical coccidiosis in lambs from ewe paddocks contaminated during successive births is less serious than that of lambs from new paddocks (Gregory et al., 1989a).

3.2. *Transmission and predisposing factors of clinical coccidiosis*

Clinical coccidiosis is a self-limiting disease. Severe disease is generally related to high infection pressure. The comparison of the excretion of oocysts between sheep and goats in the same environment has been rarely made but results from Kanyari (1993) in Kenya does not suggest a higher level of infection of one host species compared to the other.

Two conditions can lead to clinical coccidiosis: (i) massive ingestion of sporulated oocysts due to an highly infected environment (ii) and/or a significant asexual multiplication in the host, in relation to a lowered resistance of the animal. These two situations can coexist under natural conditions. Some conditions of housing or pasturing of animals (overcrowding, dampy litter, muddy zones) predispose to massive contamination of the environment and high infection pressure (Cai and Bai, 2009; Jalila et al., 1998). Moreover, all the causes of major physiological stress such as cold/heat stress or feeding (weaning and early weaning, under-feeding), associated ailments, allotments and transportation are likely to perturb the immune system. Some of these factors may be combined: coccidiosis of grazing lambs occurring about 3 weeks after turnout (Wright and Coop, 2007), higher incidence in twin or triplet lambs (Taylor, 2009). On the other hand, weaning period always shows various levels and types of stress and coccidiosis is likely to occur in young ruminants at this time (Koudela and Bokova, 1998). In Africa, the influence of seasonal factors which can be relevant both for hygienic aspects and for resistance status through nutrition is questionable: heavier excretions, during or just after the rainy season have been observed in South Africa and in Nigeria (Harper and Penzhorn, 1999; Woji et al., 1994), whereas no seasonal variation has been noticed in Kenya or in Senegal (Maingi and Munyua, 1994; Vercruysse, 1982). In Northern Europe, cold and wet weather in spring occurring in heavily stocked lowland farms predispose to clinical coccidiosis (Taylor, 2009).

The level of intensification in breeding and the related high stocking rates in premises are also predisposing factors for clinical coccidiosis (Cai and Bai, 2009; Harper and Penzhorn, 1999). This leads to a noticeable rise in the coproscopical values in animals less than one year old (61,000 opg on average as compared to 13–15,000 on extensive farms in goat in South Africa). On the other hand, the poor conditions of hygiene in the farm also determine the risk of infection. Thus Fabiyi (1980) in Nigeria, underlines the risk of keeping sheep tied at the stake during the rainy season and of feeding them from the ground.

Finally, as far as polyparasitism is concerned, a positive correlation between the excretion of coccidia oocysts and that of nematode eggs exists which suggests a similarity in contamination by the two groups of parasites (Kanyari, 1993). The resistance to coccidiosis can also be altered because of complex interactions with intercurrent digestive parasites. Thus in sheep, an anthelminthic treatment eliminating infection by *Trichostrongylus colubriformis* is accompanied by the apparition of a chronic coccidial infection with *E. ovinoidalis* which does not appear in