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Cryptosporidiosis in Animals and Man: 1. Taxonomic Classification, Life Cycle, Epidemiology and Zoonotic Importance

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ABSTRACT

Cryptosporidiosis is mainly a problem in neonatal farm animals. *Cryptosporidium parvum* is the most commonly found entero-pathogen during the 1st weeks of the life in calves, lambs, foals, piglets and goat kids and is considered to be an important agent in the etiology of the neonatal diarrhea syndrome. The parasite frequently acts alone but the losses are more pronounced when concurrent entero-pathogens are present. Economic losses associated with cryptosporidiosis are retarded growth and mortality and a number of hard to estimate costs resulting from interventions necessitated by diarrheic problems. Especially in small ruminants, the direct losses due to mortality caused by cryptosporidiosis alone were reported to be high. In the current review article, data concerning taxonomy, life cycle, epidemiology and zoonotic importance are discussed.

Key words: Cryptosporidiosis, epidemiology, animals, humans

INTRODUCTION

The genus *Cryptosporidium* was named at the beginning of the last century but was only recognized as a potential cause of disease in 1955, when it was found to be associated with diarrheic turkeys (Slavin, 1955). Although *Cryptosporidium* was subsequently found in a broad range of farm animals, its impact was neglected until the early 1980s when it was found to be a common, serious primary cause of outbreaks of diarrhea in calves (Tzipori *et al.,* 1980). The fact that *Cryptosporidium* was found to infect humans and could cause a life-threatening disease in immuno-deficient people, especially AIDS patients, as well as the association of *Cryptosporidium* with waterborne-related human outbreaks of diarrhea has certainly given the parasite a more widespread recognition (MacKenzie *et al*., 1995; Shaapan and Khalil, 2014). It has encouraged the scientific work on *Cryptosporidium* in many domains, especially in the veterinary field, because animal husbandry is seen as a threatening source of infection for humans by the release of tremendous numbers of resistant oocysts in surface water and environment. Nevertheless, the interest for cryptosporidiosis in the veterinary field arises even more from the fact that it concerns a harmful, difficult to control disease of many farm animals, which result in significant economic losses (Ramirez *et al*., 2004; Shaapan *et al*., 2011).

Cryptosporidium are intracellular, extra cytoplasmic protozoan parasites with a monoxenous life cycle. They invade the micro villous border of the gastrointestinal epithelium causing considerable economic losses in livestock. *Cryptosporidium parvum* is considered to be an

important agent in the etiology of the neonatal diarrhea syndrome in different farm animals including calves, lambs, foals, piglets and goat kids. The major economic losses due to cryptosporidial infections are related to diarrhea, dehydration, growth retardation and mortality (Olson *et al.,* 2004). A single oocyst is sufficient to produce infection and disease in susceptible hosts. Environmentally resistant oocysts are transmitted by the fecal-oral route. Transmission can occur from animal-to-animal, animal-to-person and person-to-animal and person-to-person, by ingestion of contaminated water or food or by contact with contaminated surfaces (Smith *et al*., 2007).

Therefore, the objective of the current review article was to highlight and evaluate data concerning the taxonomic classification, life cycle, epidemiology and zoonotic importance.

Developmental stages of a novel protozoan parasite were first described in the gastric glands of laboratory mice by Tyzzer (1907, 1910). The small parasites appeared to be attached to the surface of the epithelial cells by knob-like projections. Both asexual and sexual developmental stages were described to culminate in the formation of unique spores (or oocysts) containing 4 sporozoites. The parasites were considered to represent a new genus of coccidian like sporozoa which was named *Cryptosporidium* (meaning hidden sporocysts) and the species named *C. muris*. Similar parasites were later detected in the small intestines of mice by Tyzzer (1912) but they were considered to be a separate species (named *C. parvum*) because they were smaller than *C. muris* and their development was confined to the small intestinal epithelium. Despite further reports on the occurrence of *Cryptosporidium* infections in various hosts, their pathogenic significance remained unclear until Slavin (1955) described infections by a new species (named *C. meleagridis*) in the intestines of turkeys in association with acute clinical disease characterized by severe diarrhoea and low mortalities. Infection by *Cryptosporidium* spp. in cattle was first reported in the early 1970s (Panciera *et al.,* 1971; Meuten *et al.,* 1974). However, because of the association with other viral and bacterial entero-pathogens, the role of *Cryptosporidium* spp. as primary entero-pathogens was uncertain until 1980, when Tzipori *et al*. (1980) attributed an outbreak of neonatal diarrhea to cryptosporidial infection alone. In the following years methods to free the infective oocysts from other contaminating pathogens become available, which permitted the experimental demonstration that *Cryptosporidium* was capable of causing clinical diarrhoea in calves (Tzipori *et al*., 1983; Heine *et al*., 1984). In cattle, two species of the genus *Cryptosporidium* were distinguished, *C. parvum* is infecting the distal small intestine and *C. muris* infecting the abomasum. Substantial differences in the size and shape of *C. parvum* (5.0, 4.5 μm and spherical) and *C. muris* (7.4, 5.6 μm and ovoid) oocysts enables the two species to be distinguished readily on microscopical examination (Upton and Current, 1985). Only *C. parvum* has been associated with neonatal diarrhea. *Cryptosporidium muris* is much less prevalent and was only found in weaned calves or adult cattle. *Cryptosporidium muris* infection is considered to be clinically mild, affecting weight gain and milk production (Anderson, 1987; Esteban and Anderson, 1995; Bukhari and Smith, 1996). In sheep, infection by *Cryptosporidium* was first described in Australia in 1-3 week old lambs with diarrhea (Barker and Carbonell, 1974). Their roles as a primary etiological agent was confirmed in the early 1980s in studies on experimental infections in the absence of other enter pathogenic agents (Angus *et al*., 1982; Snodgrass *et al*., 1984). Since then, *Cryptosporidium* has been attributed an increasingly important role in neonatal diarrhea syndrome in this domestic species and is currently associated with high morbidity rates and mortality, depending on environmental conditions and the presence of other intestinal pathogens (Munoz *et al*., 1996). In goats, infection by this agent was also first described in Australia in 2 week

old kids with diarrhea (Mason *et al*., 1981) Since then, the infection has been diagnosed in outbreaks of diarrhoea in goat kids in several countries and is now considered to be one of the principal enteropathogens in these animals (Munoz *et al*., 1996; Noordeen *et al*., 2012). *Cryptosporidium parvum* has been associated with diarrhea in small ruminants. In a recent work, a bovine isolate of *C. muris* did not produce infection in goats (Koudela *et al.,* 1998). *Cryptosporidium* infection was first reported in pigs by Bergeland (1977) and Kennedy *et al*. (1977). Thereafter, naturally occurring cryptosporidiosis in pigs has been described worldwide (De Graaf *et al*., 1999). In humans, *Cryptosporidium* infections were reported in 1976 in two patients with severe watery diarrhea (Meisel *et al*., 1976; Nime *et al*., 1976). Additional cases were reported intermittently over the next few years, most involving immunocompromised patients who had congenital immunological disorders or were undergoing immunosuppressive therapy (Ungar, 1990; Bouzid *et al*., 3013). Further medical interest was generated in 1982 when an outbreak of cryptosporidiosis was reported in healthy immunocompetent individuals who had been in close contact with infected calves (CDC., 1982a; Current *et al*., 1983) and when chronic infections were associated with several mortalities in patients infected with Human Immunodeficiency Virus (HIV) who had developed acquired immunodeficiency syndrome (AIDS) (CDC., 1982b). Infections have since been associated with mild to severe clinical disease in both immunocompromised and immunocompetent patients throughout the world (Ungar, 1990; Current and Garcia, 1991). Currently about 30 species of the genus *Cryptosporidium* are proposed as valid. Humans and cattle are the hosts for 14 and 13 out of 30 named species, respectively. There are at least nine species that are shared between humans and cattle (Slapeta, 2013).

TAXONOMIC CLASSIFICATION

The genus Cryptosporidium has been classified in the phylum Apicomplexa, class Sporozoasida, subclass Coccidiasina, order Eucoccidiida, suborder Eimeriina, family Cryptosporidiidae (O'Donoghue, 1995). *Cryptosporidium* has been classified together with other enteric coccidian parasites in the order Eucoccidiida on the basis of many similarities in their morphological characteristics and life cycles (Table 1). Most coccidian parasites occur in the gastrointestinal tracts of vertebrates (Levine, 1985) and many genera have monoxenous life cycles involving one host species, where all stages of parasite development take place. At least 22 species of *Cryptosporidium* have been named based on host occurrence, parasite morphology, host predilection and site of infection (Table 2). However, only 13 species are considered valid by most investigators (Table 3). *Cryptosporidium parvum* is the major species responsible for disease in humans and domestic

Table 1: Taxonomic classification of *Cryptosporidium*

Classification	Characteristics
Phylum	
Apicomplexa	Apical complex present, all species parasitic
Class	
Sporozoasida	Reproduction asexual and sexual, oocysts produced
Subclass	
Coccidiasina	Life cycle generally involves merogony, gametogony and sporogony, small gamonts.
Order	
Eucoccidiorida	Merogony or schizogony present
Suborder	
Eimeriorina	Macro-and micro-gamonts develop independently; non-motile zygote.
Family	
Cryptosporidiidae	Oocysts contain four naked sporozoites (no sporocysts), endogenous stages with attachment organelle, monoxenous life cycle

*Based on classification system proposed by Levine (1985)

Table 2: List of the currently recognized species of *Cryptosporidium*

Species	Major hosts	Minor hosts	Site of infection	Dimensions of oocysts (μm)
Cryptosporidium hominis	Humans	Sheep, cattle	Small intestine	4.5×5.5
Cryptosporidium parvum	Cattle, other livestock, humans	Deer, mice, pigs	Small intestine	4.5×5.5
Cryptosporidium muris	Rodents	Humans, cattle, goats	Stomach	5.6×7.4
Cryptosporidium suis	Pigs	Humans	Small and large intestine	4.9-4.4×4-4.3
Cryptosporidium felis	Cats	Humans, cattle	Small intestine	4.5×5.0
Cryptosporidium canis	Dogs	Humans	Small intestine	4.7×4.9
Cryptosporidium meleagridis	Turkey, humans	Parrots	Small intestine	4.5-4.0×4.6-5.2
Cryptosporidium wrairi	Guinea pigs		Small intestine	4.9-5.0×4.8-5.6
Cryptosporidium bovis	Cattle	Sheep	Small intestine	4.7-5.3×4.2-4.8
Cryptosporidium andersoni	Cattle, camel	Sheep	Abomasum	5.5×7.4
Cryptosporidium baileyi	Poultry	Quails, ostriches, ducks	Bursa, cloaca, trachea	4.6×6.2
Cryptosporidium galli	Finches, chicken		Proventriculus	8.3×6.3
Cryptosporidium serpentis	Lizards, snakes		Stomach	5.6-6.6×4.8-5.6
Cryptosporidium saurophilum	Lizards	Snakes	Stomach and small intestine	4.2-5.2×4.4-5.6
Cryptosporidium scophthalmi	Fish		Intestine and stomach	3.7-5.0×3.0-4.7
Cryptosporidium molnari	Fish		Stomach and intestine	4.7×4.5

Smith *et al*. (2007)

Table 3: Valid taxonomic nomenclature of *Cryptosporidium* species and their host range

Species	Host range	Author
Cryptosporidium parvum	Mouse	Tyzzer (1912)
	Cattle	Panciera *et al*. (1971)
	Humans	Nime *et al*. (1976)
	Pig	Kennedy *et al*. (1977)
	Sheep	Barker and Carbonell (1974)
	Goat	Tzipori *et al*. (1982)
	Horse	Snyder *et al*. (1978)
Cryptosporidium hominis	Humans	Morgan-Ryan *et al*. (2002)
Cryptosporidium muris	Mouse	Tyzzer (1910)
	Humans	Katsumata *et al*. (2000)
Cryptosporidium nasorum	Fish	Hoover *et al*. (1981)
Cryptosporidium molnari	Fish	Alvarez-Pellitero and Sitja-Bobadilla (2002)
Cryptosporidium meleagridis	Turkey	Slavin (1955)
	Human	Morgan *et al*. (2000a)
Cryptosporidium baileyi	Chicken	Current *et al*. (1986)
Cryptosporidium serpentis	Snake	Levine (1980)
	Lizards	Xiao *et al*. (2004)
Cryptosporidium wrairi	Guinea pig	Vetterling *et al*. (1971)
Cryptosporidium felis	Cat	Iseki (1979)
	Humans	Pieniazek *et al*. (1999)
Cryptosporidium canis	Dog	Fayer *et al*. (2001)
	Humans	Morgan *et al*. (2000b)
Cryptosporidium andersoni	Cattle	Lindsay *et al*. (2000)
Cryptosporidium saurophilum	Lizards	Xiao *et al*. (2004)
	Snakes	Xiao *et al*. (2004)

Ramirez *et al*. (2004)

animals such as cattle, horses, sheep, goats and pigs (De Graaf *et al*., 1999). Although, phenotypic differences were traditionally used to distinguish between strains of *C. parvum* isolated from several host species, molecular epidemiological studies have demonstrated the existence of at least two unique and separate *C. parvum* genotypes, human (genotype 1) and bovine (genotype 2) (Sulaiman *et al.,* 1998). The human genotype has recently been re-classified as a different species and named *Cryptosporidium hominis* (Morgan-Ryan *et al.,* 2002) for several important reasons. *Cryptosporidium hominis* infects mainly humans while bovine *C. parvum* infections have been reported in numerous animal species including cattle, sheep, goats, pigs, mice and humans (Table 3). Morphologically, the two species are nearly indistinguishable; however, genetic

differences have been demonstrated (Morgan *et al*., 1998; Xiao *et al*., 1999). In addition, *C. parvum* and *C. hominis* showed distinctly different pathological disease patterns in gnotobiotic pigs and failed to exchange genetic material during dual infections (Pereira *et al*., 2002). *Cryptosporidium*'s unusual location within the host cell, sequestered between the cell cytoplasm and cell membrane, its ability to autoinfect, its innate antimicrobial resistance and its general lack of host specificity (especially *C. parvum*) are unique features that distinguish it from other enteric protozoa. Moreover, the taxonomy remains controversial and the epidemiology of different species is unclear, although implementation of newer molecular tools that have recently become available should help clarify *Cryptosporidium* diversity and improve our understanding of the parasite. Further studies are required to confirm the validity of *Cryptosporidium* species not only for taxonomic purposes but also for adequate diagnosis and treatment. By recent molecular and biological studies, it was found that *Cryptosporidium* is more closely related to gregarine parasites rather than to coccidians. Whereas, the identification of gregarine like gamont stages and the ability of *Cryptosporidium* to complete its life cycle in the absence of host cells further confirm its relationship with gregarines (Ryan and Hijjawi, 2015).

LIFE CYCLE

Cryptosporidium spp. have monoxenous life cycles, where all stages of development (asexual and sexual) occur within one host (Fig. 1-3). Thick-walled oocysts are excreted from the infected host in fecal material and represent the infective stage of the parasite. Infection of *Cryptosporidium*

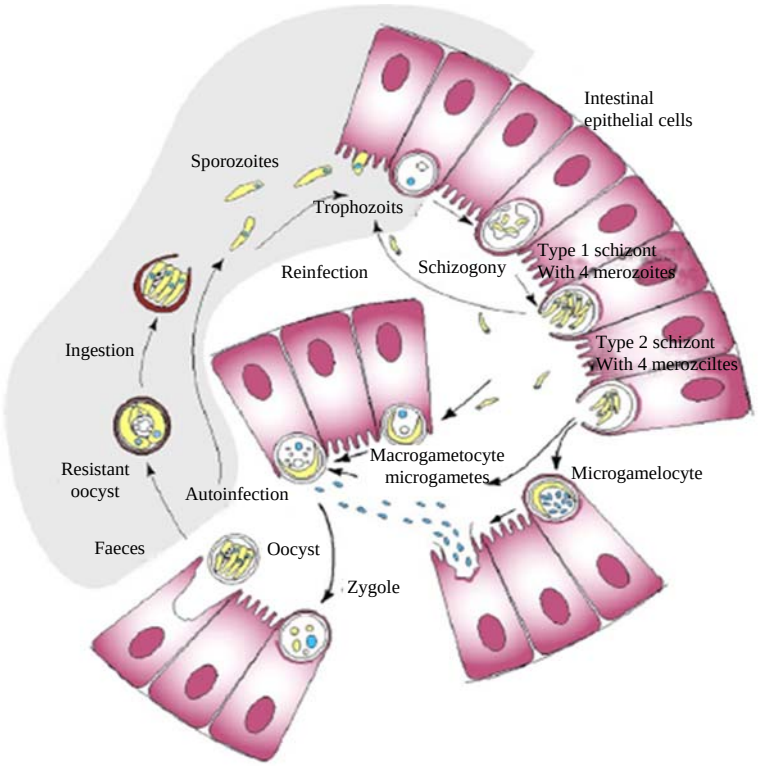

Fig. 1: Life cycle of *Cryptosporidium* in farm animals (Smith *et al*., 2007)

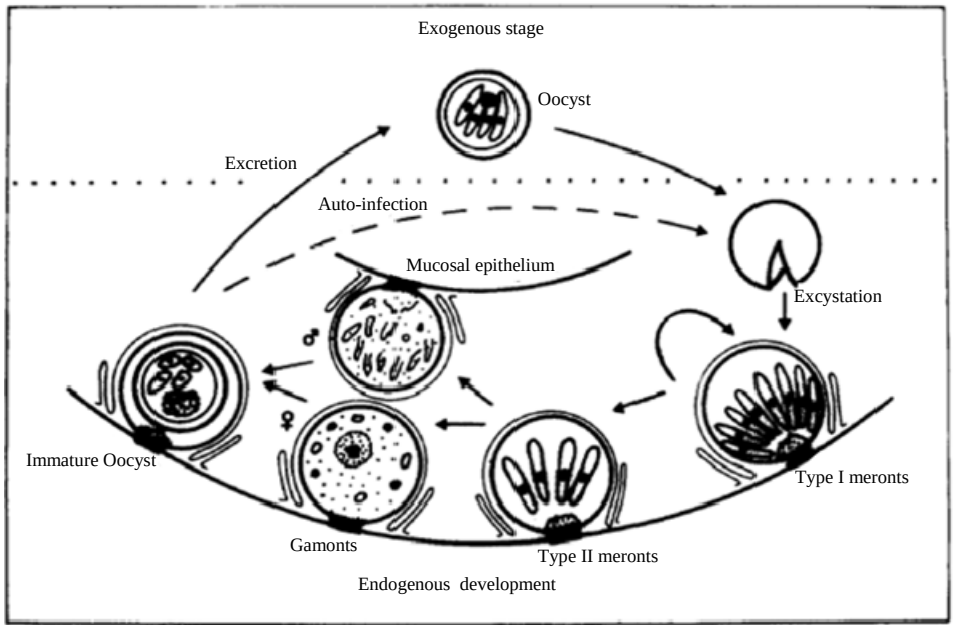

Fig. 2: *Cryptosporidium* life cycle (O'Donoghue, 1995)

in a new host results from the ingestion of these oocysts. Once they are ingested, oocysts excyst in the gastrointestinal tract releasing the infective sporozoites. Excystation has been reported to be triggered by various factors including reducing conditions, carbon dioxide, temperature, pancreatic enzymes and bile salts (Robertson *et al*., 1993). The sporozoites escape through a slit-like opening created at one end of the oocyst by dissolution of a special suture in the oocyst wall (Fayer *et al.,* 2000). The freed sporozoites attach to epithelial cells where they become enclosed within parasitophorus vacuoles and develop attachment organelles (stages generally referred as trophozoites). The trophozoites then undergo asexual proliferation by merogony (previously called schizogony). Cell division occurs by endopolygeny where multiple daughter cells are formed by internal budding within the mother meront (Fig. 2). Most studies performed on *Cryptosporidium* spp. have described sequential development involving two types of meronts (Fayer *et al*., 1997; Spano and Crisanti, 2000). Type I meronts form 8 merozoites which are liberated from the parasitophorus vacuole when mature. The merozoites then invade other epithelial cells where they undergo another cycle of type I merogony or develop into type II meronts. The type II meronts form 4 merozoites which do not undergo further merogony but produce sexual reproductive stages (called gamonts). Sexual reproduction occurs by gametogony and both microgamonts (male) and macrogamonts (female) are formed (O'Donoghue, 1995; Fayer *et al*., 1997; Collinet-Adler and Ward, 2010; Huang *et al*., 2014). Microgamonts develop into microgametocytes which produce up to 16 non-flagellated microgametes. Macrogamonts develop into uninucleate macrogametocytes which are fertilized by mature microgametes. The resultant zygotes undergo further asexual development (sporogony) leading to the production of sporulated oocysts containing 4 sporozoites (Fig. 1-3). Most oocysts (80%) are thick-walled and are excreted from the host in faecal material. Some oocysts (20%), however, there are thin-walled and have been reported to excyst within the same host animal leading to a new cycle of development (autoinfection). The presence of these

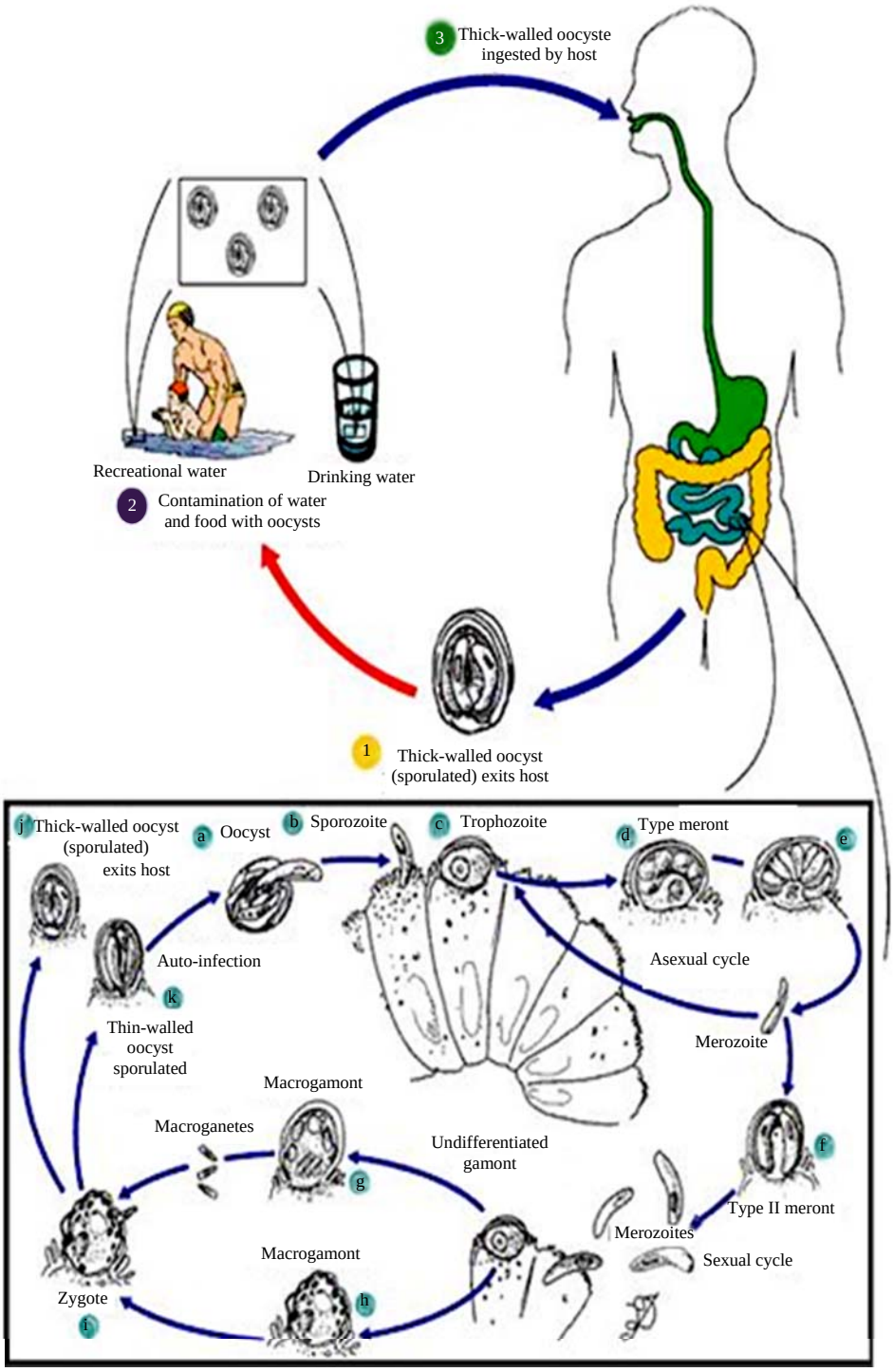

Fig. 3: Life cycle of *Cryptosporidium* in humans (Fayer *et al*., 2000)

auto-infective oocysts and recycling merozoites of type I meronts are believed to be the means by which persistent chronic infections may develop in hosts without further exposure to exogenous oocysts (Current and Garcia, 1991; Ramirez *et al*., 2004).

The entire life cycle of the parasite may be completed in as little as 2 days in many hosts and infections may be short-lived or may be persisting for several months. The prepatent period (time between infection and oocyst excretion) ranges from 1-3 weeks, whereas the patent period (duration of oocysts shedding) can range from several days to months or years, demonstrating the potential of this infection to persist. Many factors may influence the longevity of infections but the most important appear to involve the immunocompetency of the host and the parasite species involved (O'Donoghue, 1995). Compared with *Eimeria* spp., the life cycle of *Cryptosporidium* is characterized by a number of peculiarities, some of them of major importance for the establishment and spread of the infection and for the treatment of the disease: (1) Exposure of *Cryptosporidium* oocysts to reducing conditions, pancreatic enzymes and bile salts results in a high percentage of excystation. However, in contrast to most other Coccidia, *Cryptosporidium* oocysts can liberate their sporozoites in warm aqueous solutions without any of the aforementioned special stimuli (De Graaf *et al*., 1999). This spontaneous excystation explains the ability of *Cryptosporidium* to infect tissues other than the intestine, such as the conjunctiva of the eye and the respiratory tract (Mascaro *et al*., 1994; Baskin, 1996), (2) The parasite develops inside the epithelial cell of the digestive or respiratory tract, although on the edge of the host cell cytoplasm and separated from it by a feeder organelle membrane. This intracellular extra-cytoplasmic location is unique for the coccidia and might play a major role in the failure of many antimicrobial agents to inhibit the growth of *Cryptosporidium* (Tzipori and Griffiths, 1998), (3) Two stages can cause autoinfection: the recycling merozoites of type I meronts and the thin-walled oocysts. Consequently, in the absence of a protective immune response, *Cryptosporidium* may persist inside a single host even without further exposure to exogenous oocysts and (4) The thick-walled oocysts are already fully sporulated when they leave the body with the feces and are therefore immediately infectious. Thus, *Cryptosporidium* seems to have an extraordinary reproductive ability. In addition, the oocysts can travel a considerable distance following runoff can survive for a relatively long time in an aqueous environment and are infections to a wide range of animals, thus having many potential excretors. As a result, this parasite undoubtedly has an exceptional capacity to disseminate (Mawdsley *et al*., 1996; Tzipori and Griffiths, 1998).

EPIDEMIOLOGY AND INCIDENCE IN EGYPT

Among cattle, calves are susceptible to infection shortly after birth and remain so for several months. Infection in dairy calves is most often detected between 8 and 15 days of age, whereas, infection in beef calves most often occurs between 1 and 2 months of age (Garber *et al*., 1994; Ramirez *et al*., 2004). Infection in lambs and goat kids is more common in animals under 1 month old (Ortega-Mora and Wright, 1994). Fathia (1993) found that the infection rate in diarrheic calves less than 1 month was 65.5% while it was 33.3% in calves aged 1-2 months. Infection can be spread animal to animal by the fecal-oral route, usually when animals are housed together in an overcrowded environment but contamination of udder and water supplies by feces is another common source of transmission in livestock. Daily excretion of oocysts by infected lambs can exceed 2×10^9. Infected newborn calves excrete oocyst numbers of the order of 10^6-10^7 g^{-1} of feces and were considered to be a more dangerous source of infection. Moreover, adult sheep and cattle can act as asymptomatic carriers shedding small numbers of oocysts to the environment which was shown to increase in number in the perinatal period and contribute to maintaining the infection between parturition periods (Hill *et al.,* 1990; Garber *et al*., 1994; Xiao and Herd, 1994). Between 75-100% of lambs and calves born in this environment become infected in the first few weeks of life

(De Graaf *et al*., 1999). Rodents can be potential reservoirs of infection for livestock enterprises. Mechanical transmission via birds, insects and man may also be involved (Martin and Aitken, 2000). Other potential risk factors are herd size and season. In a Canadian study of beef calves, higher prevalence was found in winter and spring, the period related to calving season and consequently the period with the greatest number of calves in the high risk group (1-3 weeks old). However, in American dairy farms, where calving tend to be year-round and environmental contamination level is less subjected to fluctuations, cryptosporidiosis was more prevalent in the summer (Garber *et al*., 1994). In Egypt, several authors reported that the highest infection rate of *Cryptosporidium* among calves and lambs was in summer and spring and the lowest was in autumn and winter (Abdel-Salam *et al*., 1993; Fathia, 1993; Lubna, 1993; Aboul-Khir, 1996). Milk can be contaminated through mechanism of poor udder hygiene and recent outbreaks of human cryptosporidiosis associated with drinking unpasteurized milk have been reported (Harper *et al*., 2002). Furthermore, the large number of oocysts excreted during infection helps to ensure a high level of environmental contamination. Cattle facilities are frequently blamed when *Cryptosporidium* is found in surface water. Thus, cattle living in close proximity to rivers should be considered potential causes of waterborne contamination, as surface run-off does transport *Cryptosporidium* oocysts in soils to water sources. *Cryptosporidium* oocysts have been recovered from untreated surface water (rivers, streams and reservoirs), untreated and treated sewage effluents, filtered swimming pool water and most importantly from treated drinking water supplies (Richardson *et al*., 1991). Another risk factor identified for increasing probability of calves shedding oocysts is frequent bedding changes as personnel and equipment used for removal of the bedding can actually become a vehicle for spreading the infection (Sischo *et al*., 2000). In Egypt, cryptosporidiosis was reported in farm animals by many authors in different localities. In Sohag, Abdel-Salam *et al*. (1993) reported a high prevalence level of 33.9% in diarrhoeic calves less than one month age. In Ismailia, Abou-Eisha (1994) found that 36.6, 24.0 and 21.3% of diarrhoeic buffalo-calves, lambs and goat kids, up to one month age were infected with *Cryptosporidium* oocysts, respectively. Moreover, Abou-Eisha (1994) detected *Cryptosporidium* oocysts for the first time in Egypt from a calf camel aged less than one month. Abou El-Hassan (1996) in Giza, found that 16.5% of diarrhoeic goat kids were positive for *Cryptosporidia*. Ghazy *et al*. (2004) revealed a prevalence level of 46.3% in foals suffering from emaciation, anemia, recurrent colic and chronic intermittent diarrhea.

INFECTION IN HUMANS AND ZOONOTIC IMPORTANCE

Contaminated water represents the major source of *Cryptosporidium* infections for humans (Fig. 3). Several waterborne outbreaks of cryptosporidiosis have been reported implicating contaminated drinking water and recreational water (Kramer *et al*., 1998). The most severe and largest human waterborne outbreak occurred in Milwaukee in 1993, where more than 400,000 people were infected (MacKenzie *et al.,* 1995). In the search for sources of waterborne outbreaks of cryptosporidiosis, livestock have often been implicated as the origin of contaminating isolate (Olson *et al*., 2004). Cryptosporidiosis in humans typically manifests itself as a self-limiting disease with a median duration of 9-15 days, resulting in total recovering in healthy individuals. The major symptoms are watery diarrhea associated with abdominal cramps, anorexia, weight loss, nausea, vomiting, fatigue and low-grade fever (Marshall and LaMont, 1997). Symptoms are similar in children and adults, although cryptosporidiosis acquired during infancy may have permanent effects on growth and development (Molbak *et al*., 1997). However, it is in the immunocompromised

host (due to a variety of causes including but not limited to HIV infection and AIDS, drugs, organ transplantation, cancer chemotherapy, etc.) that the infections are most chronic and debilitating (Farthing, 2000). Patients can have chronic diarrhea that can last for more than 2 months, shed oocysts in stool during the entire period, contributing to severe dehydration, weight loss and malnutrition, extended hospitalization and mortality (Ramirez *et al*., 2004). Thus, the severity and duration of illness depends on the host's immune status. The groups implicated with higher risks of infection include children and staff in day care centers, farmers and animal handlers and health care workers. Travelers are at risk when they travel from developed to developing countries with high prevalence of the disease.

At least nine molecularly different types of *Cryptosporidium* have been found to infect humans (Table 4 and Fig. 4). *Cryptosporidium hominis* and *C. parvum* are responsible for the majority of infections in humans (Ryan and Hijjawi, 2015). Excluding *C. parvum* pig genotype and *C. muris*, infection with these species have been reported not only in HIV positive individuals but also in immunocompetent children and adults (Katsumata *et al*., 2000; Morgan *et al*., 2000a; Xiao *et al*., 2001, 2002; Morgan-Ryan *et al*., 2002; Mallon *et al*., 2003; Palmer *et al*., 2003). In the US, most human cryptosporidiosis cases are caused by *C. hominis* (>75%). However, in the UK bovine *C. parvum* is responsible for 61.5% of human cases and 37.8% of human cryptosporidiosis was caused by *C. hominis* (Peng *et al*., 1997; Sulaiman *et al*., 1998; McLauchlin *et al*., 2000). These differences may be due to the obvious separation between urban and rural populations in the US, compared to the UK where communities are closely related to agricultural sources (Hunter *et al*., 2003; Smerdon *et al*., 2003). The human genotype is also notably predominant in Australia, Kenya, Guatemala and Peru, since it is responsible for 85-92% of the human infections (Xiao *et al*., 2000). In Egypt, Habib (1985) and Mabrouk (1986) found that *C. parvum* were presented in 9-11.7% of diarrhoeic children. Out of which 60% were coming from urban area and 40% from rural area. They added that 17.2% of the positive cases had a history of contact with animals. Selim (1995) identified *Cryptosporidium* oocysts from 4.5% of humans in contact with infected animals (sheep, goats, dogs and cats).

Table 4: *Cryptosporidium* species capable of causing infections in humans (Rimhanen-Finne, 2006)

Species	Original host	References
Cryptosporidium hominis	Human	Morgan-Ryan *et al*. (2002)
Cryptosporidium parvum	House mouse	Tyzzer (1910)
Cryptosporidium baileyi	Chicken	Ditrich *et al*. (1991)
Cryptosporidium meleagridis	Turkey	Pedraza-Diaz *et al*. (2001a) and Xiao *et al*. (2001)
Cryptosporidium felis	Cat	Caccio *et al*. (2002)
Cryptosporidium canis	Dog	Pedraza-Diaz *et al*. (2001b) and Xiao *et al*. (2001)
Cryptosporidium suis	Pig	Xiao *et al*. (2002)
Cryptosporidium muris	House mouse	Palmer *et al*. (2003)

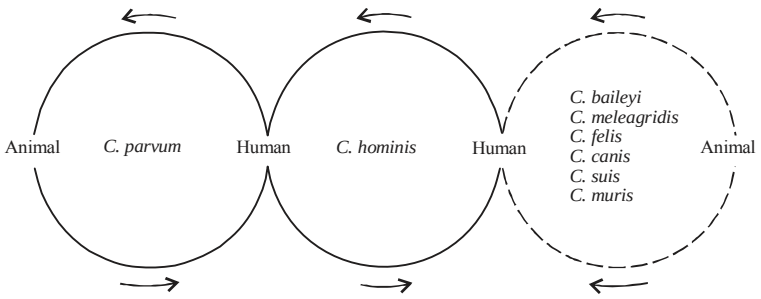

Fig 4: Transmission cycles of human *Cryptosporidium* infections. Dotted cycle demonstrates rare transmission (Rimhanen-Finne, 2006)

Humans have close interactions with companion animals, sharing their living space and consequently, sharing microorganisms that may cause disease. Most commonly, people have cats, dogs and birds but fish, lizards, snakes, ferrets and other exotic animals are also frequent household pets. The occurrence of *Cryptosporidium* in dogs, cats and other pets has been described in the study of Morgan *et al.* (2000b) and Fayer *et al*. (2001). *Cryptosporidium* infection in dogs is generally asymptomatic. Dogs less than 6 months of age are affected more often than the adults. By comparison, in a report of *Cryptosporidium* in cats, 50% of infected cats showed diarrhea symptoms (Hill *et al*., 2000). Zoonotic cryptosporidiosis from exposure to pets has not been documented in healthy adults but transmission of (bovine) *C. parvum* from companion (cats, dogs) to HIV-infected persons has been reported (Meisel *et al*., 1976). In addition, other *Cryptosporidium* species such as *C. felis, C. canis* and *C. meleagridis* (Fig. 4) have also been recorded to infect healthy children and adults (Pedraza-Diaz *et al*., 2001a, b; Xiao *et al*., 2001). The concern of acquiring cryptosporidiosis from pets is more serious for children, the elderly and immunocompromised individuals; however, one report suggests that pets are not a major risk factor (Glaser *et al*., 1998). Veterinarians are the best-suited professionals to provide accurate advise to persons about the risk of *Cryptosporidium* infection from their pets and what measures should be taken to minimize the occurrence of cryptosporidiosis in animals, especially to owners of high risk (i.e. immunocompromised) (Irwin, 2002).

CONCLUSION

The genus *Cryptosporidium* has been classified in the phylum Apicomplexa, class Sporozoasida, subclass Coccidiasina, order Eucoccidiida, suborder Eimeriina, family Cryptosporidiidae. *Cryptosporidium* spp. has monoxenous life cycles, where all stages of development (asexual and sexual) occur within one host. Infection in dairy calves is most often detected between 8 and 15 days of age, whereas infection in beef calves most often occurs between 1 and 2 months of age. Infection in lambs and goat kids is more common in animals under 1 month old. Rodents can be potential reservoirs of infection for livestock enterprises. Mechanical transmission via birds, insects and man may also be involved.

REFERENCES

Abdel-Salam, F.A., H.S. Ali and A.A. Galal, 1993. Some studies on cryposporidiosis in calves in Sohag Governorate. Assuit Vet. Med. J., 29: 151-163.

Abou El-Hassan, A., 1996. Neonatal diarrhoea in lambs and goat kids. Vet. Med. J. Giza, 44: 371-380.

Abou-Eisha, A.M., 1994. Cryptosporidial infection in man and farm animals in Ismailia governorate. Vet. Med. J., 42: 107-111.

Aboul-Khir, E.A.M., 1996. Biological immunological studies on *Cryptosporidia* parasite. Ph.D. Thesis, Faculty of Veterinary Medicine, Cairo University, Egypt.

Alvarez-Pellitero, P. and A. Sitja-Bobadilla, 2002. *Cryptosporidium molnari* n. sp. (Apicomplexa: Cryptosporidiidae) infecting two marine fish species, *Sparus aurata* L. and *Dicentrarchus labrax* L. Int. J. Parasitol., 32: 1007-1021.

Anderson, B.C., 1987. Abomasal cryptosporidiosis in cattle. Vet. Pathol., 24: 235-238.

Angus, K.W., S. Tzipori and E.W. Gray, 1982. Intestinal lesions in specific-pathogen-free lambs associated with a cryptosporidium from calves with diarrhea. Vet. Parasitol., 19: 67-78.

Barker, I.K. and P.L. Carbonell, 1974. *Cryptosporidium agni* sp.n. from lambs and *Cryptosporidium bovis* sp.n. from a calf, with observations on the oocyst. Zeitschrift Parasitenkunde, 44: 289-298.

Baskin, G.B., 1996. Cryptosporidiosis of the conjunctiva in SIV-infected rhesus monkeys. J. Parasitol., 82: 630-632.

Bergeland, M.E., 1977. Necrotic enteritis in nursing piglets. Proc. Am. Assoc. Vet. Lab. Diagn., 20: 151-158.

Bouzid, M., P.R. Hunter, R.M. Chalmers and K.M. Tyler, 2013. *Cryptosporidium* pathogenicity and virulence. Clin. Microbiol. Rev., 26: 115-134.

Bukhari, Z. and H.V. Smith, 1996. Detection of *Cryptosporidium muris* oocysts in the faeces of adult dairy cattle in Scotland. Vet. Rec., 138: 207-208.

CDC., 1982a. Cryptosporidiosis: Assessment of chemotherapy of males with Acquired Immune Deficiency Syndrome (AIDS). MMWR Morbidity Mortality Weekly Rep., 31: 589-592.

CDC., 1 982b. Human cryptosporidiosis-Alabama. MMWR Morbidity Mortality Weekly Rep., 31: 252-254.

Caccio, S., E. Pinter, R. Fantini, I. Mezzaroma and E. Pozio, 2002. Human infection with *Cryptosporidium felis*: Case report and literature review. Emerg. Infect. Dis., 8: 85-86.

Collinet-Adler, S. and H.D. Ward, 2010. Cryptosporidiosis: Environmental, therapeutic and preventive challenges. Eur. J. Clin. Microbiol. Infect. Dis., 29: 927-935.

Current, W.L., N.C. Reese, J.V. Ernst, W.S. Bailey, M.B. Heyman and W.M. Weinstein, 1983. Human cryptosporidiosis in immunocompetent and immunodeficient persons-studies of an outbreak and experimental transmission. N. Engl. J. Med., 308: 1252-1257.

Current, W.L., S.J. Upton and T.B. Haynes, 1986. The life cycle of *Cryptosporidium baileyi* n. sp. (Apicomplexa, Cryptosporidiidae) infecting chickens. J. Protozool., 33: 289-296.

Current, W.L. and L.S. Garcia, 1991. Cryptosporidiosis. Clin. Microbiol. Rev., 4: 325-358.

De Graaf, D.C., E. Vanopdenbosch, L.M. Ortega-Mora, H. Abbassi and J.E. Peeters, 1999. A review of the importance of cryptosporidiosis in farm animals. Int. J. Parasitol., 29: 1269-1287.

Ditrich, O., L. Palkovic, J. Sterba, J. Prokopic, J. Loudova and M. Giboda, 1991. The first finding of *Cryptosporidium baileyi* in man. Parasitol. Res., 77: 44-47.

Esteban, E. and B.C. Anderson, 1995. *Cryptosporidium muris*: Prevalence, persistency and detrimental effect on milk production in a drylot dairy. J. Dairy Sci., 78: 1068-1072.

Farthing, M.J.G., 2000. Clinical aspects of human cryptosporidiosis. Contrib. Microbiol., 6: 50-74.

Fathia, A.K., 1993. Studies on *Cryptosporidium* in calves. M.V.Sc. Thesis, Faculty of Veterinary Medicine, Cairo University, Egypt.

Fayer, R., C.A. Speer and J.P. Dubey, 1997. The General Biology of *Cryptosporidium*. In: *Cryptosporidium* and Cryptosporidiosis, Fayer, R. (Ed.). CRC Press, Boca Raton, USA., pp: 1-42.

Fayer, R., U. Morgan and S.J. Upton, 2000. Epidemiology of *Cryptosporidium*: Transmission, detection and identification. Int. J. Parasitol., 30: 1305-1322.

Fayer, R., J.M. Trout, L. Xiao, U.M. Morgan, A.A. Lai and J.P. Dubey, 2001. *Cryptosporidium canis* n. sp. from domestic dogs. J. Parasitol., 87: 1415-1422.

Garber, L.P., M.D. Salman, H.S. Hurd, T. Keefe and J.L. Schlater, 1994. Potential risk factors for *Cryptosporidium* infection in dairy calves. J. Am. Vet. Med. Assoc., 205: 86-91.

Ghazy, A.A., F.A.M. Khalil and H. Soufy, 2004. Studies on equine cryptosporidiosis among farm horses in Egypt. J. Egypt. Vet. Med. Assoc., 64: 201-214.

Glaser, C.A., S. Safrin, A. Reingold and T.B. Newman, 1998. Association between *Cryptosporidium* infection and animal exposure in HIV-infected individuals. J. Acquired Immune Deficiency Syndromes Hum. Retrovirol., 17: 79-82.

Habib, F.S.M., 1985. *Cryptosporidiosis* as a possible cause of diarrhoea in children. M.Sc. Thesis, Faculty of Medicine, Ain Shams University, Cairo, Egypt.

Harper, C.M., N.A. Cowell, B.C. Adams, A.J. Langley and T.D. Wohlsen, 2002. Outbreak of *Cryptosporidium* linked to drinking unpasteurised milk. Commun. Dis. Intell. Q. Rep., 26: 449-450.

Heine, J., J.F.L. Pohlenz, H.W. Moon and G.N. Woode, 1984. Enteric lesions and diarrhea in gnotobiotic calves monoinfected with *Cryptosporidium* species. J. Infect. Dis., 150: 768-775.

Hill, B.D., D.A. Blewett, A.M. Dawson and S. Wright, 1990. Analysis of the kinetics, isotype and specificity of serum and coproantibody in lambs infected with *Cryptosporidium parvum*. Res. Vet. Sci., 48: 76-81.

Hill, S.L., J.M. Cheney, G.F. Taton-Allen, J.S. Reif, C. Bruns and M.R. Lappin, 2000. Prevalence of enteric zoonotic organisms in cats. J. Am. Vet. Med. Assoc., 216: 687-692.

Hoover, D.M., F.J. Hoerr, W.W. Carlton, E.J. Hisman and H.W. Fergusin, 1981. Enteric cryptosporidiosis in a naso tang, *Naso lituratus* Bloch and Schneider. J. Fish Dis., 4: 425-428.

Huang, L., H. Zhu, S. Zhang, R. Wang and L. Liu *et al*., 2014. An *in vitro* model of infection of chicken embryos by *Cryptosporidium baileyi*. Exp. Parasitol., 147: 41-47.

Hunter, P.R., R.M. Chalmers, Q. Syed, L.S. Hughes, S. Woodehouse and L. Swift, 2003. Foot and mouth disease and cryptosporidiosis: Possible interaction between two emerging infectious diseases. Emerg. Infect. Dis., 9: 109-112.

Irwin, P.J., 2002. Companion animal parasitology: A clinical perspective. Int. J. Parasitol., 32: 581-593.

Iseki, M., 1979. *Cryptosporidium felis* sp. n. (Protozoa: Eimeriorina) from the domestic cat. Jpn. J. Parasitol., 28: 285-307.

Katsumata, T., D. Hosea, I.G. Ranuh, S. Uga, T. Yanagi and S. Kohno, 2000. Short report: Possible *Cryptosporidium muris* infection in humans. Am. J. Trop. Med. Hyg., 62: 70-72.

Kennedy, G.A., G.L. Kreinter and A.C. Strafuss, 1977. *Cryptosporidiosis* in three pigs. J. Am. Vet. Med. Assoc., 170: 348-350.

Koudela, B., D. Modry and J. Vitovec, 1998. Infectivity of *Cryptosporidium muris* isolated from cattle. Vet. Parasitol., 76: 181-188.

Kramer, M.H., F.E. Sorhage, S.T. Goldstein, E. Dalley, S.P. Wahlquist and B.L. Herwaldt, 1998. First reported outbreak in the United States of cryptosporidiosis associated with a recreational lake. Clin. Infect. Dis., 26: 27-33.

Levine, N.D., 1980. Some corrections of coccidian (Apicomplexa: Protozoa) nomenclature. J. Parasitol., 66: 830-834.

Levine, N.D., 1985. Phylum II Apicomplexa Levine, 1970. In: An Illustrated Guide to the Protozoa, Lee, J.J., S.H. Humter and E.C. Bovee (Eds.). Allen Press, Lawrence, pp: 322-374.

Lindsay, D.S., S.J. Upton, D.S. Owens, U.M. Morgan, J.R. Mead and B.L. Blagburn, 2000. *Cryptosporidium andersoni* n. sp. (Apicomplexa: Cryptosporiidae) from cattle, *Bos taurus*. J. Eukaryotic Microbiol., 47: 91-95.

Lubna, M.I.E., 1993. Studies on *Coccidia* species infecting sheep in Kalubia Governorate. Ph.D. Thesis, Faculty Veterinary Medicine, Zagazig University, Benha Branch, Egypt.

Mabrouk, A.N.K., 1986. Cryptosporidiosis among diarrhoeic children. M.Sc. Thesis, Faculty Veterinary Medicine, Alexandria University, Egypt.

MacKenzie, W.R., W.L. Schell, K.A. Blair, D.G. Addiss and D.E. Peterson *et al*., 1995. Massive outbreak of waterborne cryptosporidium infection in Milwaukee, Wisconsin: Recurrence of illness and risk of secondary transmission. Clin. Infect. Dis., 21: 57-62.

Mallon, M.E., A. MacLeod, J.M. Wasting, H. Smith and A. Tait, 2003. Multilocus genotyping of *Cryptosporidium parvum* type 2: Population genetics and sub-structuring. Infect. Genet. Evol., 3: 207-218.

Marshall, A.T. and J.T. LaMont, 1997. Cryptosporidiosis and public health. Hosp. Pract., 32: 15-16.

Martin, W.B. and I.D. Aitken, 2000. Diseases of Sheep. 3rd Edn., Blackwell Science Ltd., UK., pp: 153-159.

Mascaro, C., T. Arnedo and M.J. Rosales, 1994. Respiratory cryptosporidiosis in a bovine. J. Parasitol., 80: 334-336.

Mason, R.W., W.J. Hartley and L. Tilt, 1981. Intestinal cryptosporidiosis in a kid goat. Aust. Vet. J., 57: 386-388.

Mawdsley, J.L., A.E. Brooks, P.J. Merry and B.F. Pain, 1996. Use of a novel soil tilting table apparatus to demonstrate the horizontal and vertical movement of the protozoan pathogen *Cryptosporidium parvum* in soil. Biol. Fertil. Soils, 23: 215-220.

McLauchlin, J., C. Amar, S. Pedraza-Diaz and G.L. Nichols, 2000. Molecular epidemiological analysis of *Cryptosporidium* spp. in the United Kingdom: Results of genotyping *Cryptosporidium* spp. in 1,705 fecal samples from humans and 105 fecal samples from livestock animals. J. Clin. Microbiol., 38: 3984-3990.

Meisel, J.L., D.R. Perera, C. Meligro and C.E. Rubin, 1976. Overwhelming watery diarrhea associated with a cryptosporidium in an immunosuppressed patient. Gastroenterology, 70: 1156-1160.

Meuten, D.J., H.J. van Kruiningen and D.H. Lein, 1974. Cryptosporidiosis in a calf. J. Am. Vet. Med. Assoc., 165: 914-917.

Molbak, K., M. Andersen P. Aaby, N. Hojlyng, M. Jakobsen and A.P. da Silva, 1997. *Cryptosporidium* infection in infancy as a cause of malnutrition: A community study from Guinea-Bissau, West Africa. Am. J. Clin. Nutr., 65: 149-152.

Morgan, U.M., K.D. Sargent, P. Deplazes, D.A. Forbes and F. Spano *et al*., 1998. Molecular characterization of *Cryptosporidium* from various hosts. Parasitology, 117: 31-37.

Morgan, U., R. Weber, L. Xiao, I. Sulaiman and R.C.A. Thompson *et al*., 2000a. Molecular characterization of *Cryptosporidium* isolates obtained from human immunodeficiency virus-infected individuals living in Switzerland, Kenya and the United States. J. Clin. Microbiol., 38: 1180-1183.

Morgan, U.M., L. Xiao, P. Monis, A. Fall and P.J. Irwin *et al*., 2000b. *Cryptosporidium* spp. in domestic dogs: The dog genotype. Applied Environ. Microbiol., 66: 2220-2223.

Morgan-Ryan, U.M., A. Fall, L.A. Ward, N. Hijjawi and I. Sulaiman *et al*., 2002. *Cryptosporidium hominis* n. sp. (Apicomplexa: Cryptosporidiidae) from *Homo sapiens*. J. Eukaryotic Microbiol., 49: 433-440.

Munoz, M., M. Alvarez, I. Lanza and P. Carmenes, 1996. Role of enteric pathogens in the aetiology of neonatal diarrhoea in lambs and goat kids in Spain. Epidemiol. Infect., 117: 203-211.

Nime, F.A., J.D. Burek, D.L. Page, M.A. Holscher and J.H. Yardley, 1976. Acute enterocolitis in a human being infected with the protozoan *Cryptosporidium*. Gastroenterology, 70: 592-598.

Noordeen, F., R.P.V.J. Rajapakse, N.U. Horadagoda, M.F. Abdul-Careem and A. Arulkanthan, 2012. *Cryptosporidium*, an important enteric pathogen in goats-a review. Small Rumin. Res., 106: 77-82.

O'Donoghue, P.J., 1995. Cryptosporidium and cryptosporidiosis in man and animals. Int. J. Parasitol., 25: 139-195.

Olson, M.E., R.M. O'Handley, B.J. Ralston, T.A. McAllister and R.C.A. Thompson, 2004. Update on *Cryptosporidium* and *Giardia* infections in cattle. Trends Parasitol., 20: 185-191.

Ortega-Mora, L.M. and S.E. Wright, 1994. Age-related resistance in ovine cryptosporidiosis: Patterns of infection and humoral immune response. Infect. Immunity, 62: 5003-5009.

Palmer, C.J., L. Xiao, A. Terashima, H. Guerra and E. Gotuzzo *et al*., 2003. *Cryptosporidium muris*, a rodent pathogen, recovered from a human in Peru. Emerg. Infect. Dis., 9: 1174-1176.

Panciera, R.J., R.W. Thomassen and F.M. Garner, 1971. Cryptosporidial infection in a calf. Vet. Pathol., 8: 479-484.

Pedraza-Diaz, S., C. Amar, A.M. Iversen, P.J. Stanley and J. McLauchlin, 2001a. Unusual *Cryptosporidium* species recovered from human faeces: First description of *Cryptosporidium felis* and *Cryptosporidium* dog type from patients in England. J. Med. Microbiol., 50: 293-296.

Pedraza-Diaz, S., C.F.L. Amar, J. McLauchlin, G.L. Nichols and K.M. Cotton *et al*., 2001b. *Cryptosporidium meleagridis* from humans: Molecular analysis and description of affected patients. J. Infect., 42: 243-250.

Peng, M.M., L. Xiao, A.R. Freeman, M.J. Arrowood and A.A. Escalante *et al*., 1997. Genetic polymorphism among *Cryptosporidium parvum* isolates: Evidence of two distinct human transmission cycles. Emerg. Infect. Dis., 3: 567-573.

Pereira, S.J., N.E. Ramirez, L. Xiao and L.A. Ward, 2002. Pathogenesis of human and bovine *Cryptosporidium parvum* in gnotobiotic pigs. J. Infect. Dis., 186: 715-718.

Pieniazek, N.J., F.J. Bornay-Llinares, S.B. Slemenda, A.J. da Silva and I.N.S. Moura *et al*., 1999. New *Cryptosporidium* genotypes in HIV-infected persons. Emerg. Infect. Dis., 5: 444-449.

Ramirez, N.E., L.A. Ward and S.A. Sreevatsan, 2004. A review of the biology and epidemiology of cryptosporidiosis in humans and animals. Microb. Infect., 6: 773-785.

Richardson, A.J., R.A. Frankenberg, A.C. Buck, J.B. Selkon, J.S. Colbourne, J.W. Parsons and R.T. Mayon-White, 1991. An outbreak of waterborne cryptosporidiosis in Swindon and Oxfordshire. Epidemiol. Infect., 107: 485-495.

Rimhanen-Finne, R., 2006. *Cryptosporidium* and *Giardia*: Detection in Environmental and Faecal Samples. Faculty of Veterinary Medicine, University of Helsinki, Finland, ISBN: 9789529198085, pp: 12-29.

Robertson, L.J., A.T. Campbell and H.V. Smith, 1993. *In vitro* excystation of *Cryptosporidium parvum*. Parasitology, 106: 13-19.

Ryan, U. and N. Hijjawi, 2015. New developments in *Cryptosporidium* research. Int. J. Parasitol., 45: 367-373.

Selim, A.M., 1995. Prevalence of cryptosporidiosis in animals and human beings in contact in Sharkia province. Alex. J. Vet. Sci., 11: 527-533.

Shaapan, R., F.A.M. Khalil and M.T.A.E.E. Nadia, 2011. *Cryptosporidiosis* and *Toxoplasmosis* in native quails of Egypt. Res. J. Vet. Sci., 4: 30-36.

Shaapan, R. and F. Khalil, 2014. Zoonotic Significance of Cryptosporidiosis. LAMBERT Academic Publishing, Saarbrucken, Germany, ISBN-13: 978-3-659-53506-2, Pages: 68.

Sischo, W.M., E.R. Atwill, L.E. Lanyon and J. George, 2000. Cryptosporidia on dairy farms and the role these farms may have in contaminating surface water supplies in the Northeastern United States. Prev. Vet. Med., 43: 253-267.

Slapeta, J., 2013. Cryptosporidiosis and *Cryptosporidium* species in animals and humans: A thirty colour rainbow? Int. J. Parasitol., 43: 957-970.

Slavin, D., 1955. *Cryptosporidium meleagridis* (sp. nov.). J. Comp. Pathol. Therapeut., 65: 262-266.

Smerdon, W.J., T. Nichols, R.M. Chalmers, H. Heine and M. Reacher, 2003. Foot and mouth disease in livestock and reduced cryptosporidiosis in humans, England and Wales. Emerg. Infect. Dis., 9: 22-28.

Smith, H.V., S.M. Caccio, N. Cook, R.A.B. Nichols and A. Tait, 2007. *Cryptosporidium* and *Giardia* as foodborne zoonoses. Vet. Parasitol., 149: 29-40.

Snodgrass, D.R., K.W. Angus and E.W. Gray, 1984. Experimental cryptosporidiosis in germfree lambs. J. Comp. Pathol., 94: 141-152.

Snyder, S.P., J.J. England and A.E. McChesney, 1978. Cryptosporidiosis in immunodeficient Arabian foals. Vet. Pathol., 15: 12-17.

Spano, F. and A. Crisanti, 2000. *Cryptosporidium parvum*: The many secrets of a small genome. Int. J. Parasitol., 30: 553-565.

Sulaiman, I.M., L. Xiao, C. Yang, L. Escalante and A. Moore *et al*., 1998. Differentiating human from animal isolates of *Cryptosporidium parvum*. Emerg. Infect. Dis., 4: 681-685.

Tyzzer, E.E., 1907. A sporozoan found in the peptic glands of the common mouse. Exp. Biol. Med., 56: 12-13.

Tyzzer, E.E., 1910. An extracellular coccidium, *Cryptosporidium muris* (Gen. Et Sp. Nov.), of the gastric glands of the common mouse. J. Med. Res., 23: 487-510.

Tyzzer, E.E., 1912. *Cryptosporidium parvum* (sp. nov), a coccidian found in the small intestine of the common mouse. Archiv Prtistenkunde, 26: 394-412.

Tzipori, S., I. Campbell, D. Sherwood, D.R. Snodgrass and A. Whitelaw, 1980. An outbreak of calf diarrhoea attributed to cryptosporidial infection. Vet. Rec., 107: 579-580.

Tzipori, S., M. Smith, T. Makin and C. Halpin, 1982. Enterocolitis in piglets caused by *Cryptosporidium* sp. purified from calf faeces. Vet. Parasitol., 11: 121-126.

Tzipori, S., M. Smith, C. Halpin, K.W. Angus, D. Sherwood and I. Campbell, 1983. Experimental cryptosporidiosis in calves: Clinical manifestations and pathological findings. Vet. Rec., 112: 116-120.

Tzipori, S. and J.K. Griffiths, 1998. Natural history and biology of *Cryptosporidium parvum*. Adv. Parasitol., 40: 5-36.

Ungar, B.L.P., 1990. Cryptosporidiosis in Humans (*Homo sapiens*). In: Cryptosporidiosis on Man and Animals, Dubey, J.P., C.A. Speer and R. Fayer (Eds.). CRC Press, New York, USA., ISBN-13: 9780849364013, pp: 59-82.

Upton, S.J. and W.L. Current, 1985. The species of *Cryptosporidium* (Apicomplexa: Cryptosporidiidae) infecting mammals. J. Parasitol., 71: 625-629.

Vetterling, J.M., H.R. Jervis, T.G. Merrill and H. Sprinz, 1971. *Cryptosporidium wrairi* sp. n. from the guinea pig *Cavia porcellus*, with an emendation of the genus. J. Protozool., 18: 243-247.

Xiao, L. and R.P. Herd, 1994. Infection patterns of *Cryptosporidium* and *Giardia* in calves. Vet. Parasitol., 55: 257-262.

Xiao, L., U.M. Morgan, J. Limor, A. Escalante and M. Arrowood *et al*., 1999. Genetic diversity within *Cryptosporidium* parvum and related *Cryptosporidium* species. Applied Environ. Microbiol., 65: 3386-3391.

Xiao, L., U.M. Morgan, R. Fayer, R.C.A. Thompson and A.A. Lal, 2000. *Cryptosporidium* systematics and implications for public health. Parasitol. Today, 16: 287-292.

Xiao, L., C. Bern, J. Limor, I. Sulaiman and J. Roberts *et al*., 2001. Identification of 5 types of *Cryptosporidium* parasites in children in Lima, Peru. J. Infect. Dis., 183: 492-497.

Xiao, L., C. Bern, M. Arrowood, I. Sulaiman and L. Zhou *et al*., 2002. Identification of the *Cryptosporidium* pig genotype in a human patient. J. Infect. Dis., 185: 1846-1847.

Xiao, L., U.M. Ryan, T.K. Graczyk, J. Limor and L. Li *et al*., 2004. Genetic diversity of *Cryptosporidium* spp. in captive reptiles. Applied Environ. Microbiol., 70: 891-899.