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Proposal for a New Nomenclature of the *Sarcosporidia**

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The position of the sarcosporidia within the zoological system has been doubtful for many decades. Only the electron microscopical examination of the fine structure of various developmental stages of *Toxoplasma*, *Sarcocystis*, *Besnoitia*, and *Frenkelia* and the comparison with other Sporozoa allowed the classification of the sarcosporidia as Sporozoa (lit. cit. Scholtyseck, Mehlhorn, 1973). A further definitive classification has not been possible because the life cycles of the sarcosporidia were not known. The results of the electron microscopical examination, however, allowed coccidian-like life cycles to be suggested for the sarcosporidia.

This suggestion was supported by the work of Fayer (1970, 1972) who succeeded in observing the development of sarcosporidian zoites from the muscle cysts of the grackle (*Quiscalus quiscula*) in cell cultures up to the formation of macro- and microgametes and oocyst-like structures. The final proof of the coccidian-like nature of this parasite was achieved by a series of transmission experiments with the sarcosporidia of sheep, cattle, and pigs. In these experiments the sarcosporidia within the muscles of the above mentioned three animal species were shown to be developmental stages of already known *Isospora* species of cats, dogs, and of man (Rommel *et al.*, 1972; Heydorn, Rommel, 1972a, b; Rommel, Heydorn, 1972, 1974).

These findings were confirmed by a number of authors in the following years (Fayer, Leek, 1973; Mahrt, 1973; Vershinin, 1973; Fayer, 1974; Ford, 1974; Mehlhorn, Scholtyseck, 1974; Munday, Corbould, 1974). Not only mammals were shown to be final hosts of sarcosporidia, but also reptiles. Rzepczyk (1974) observed a rat (*Rattus fuscipes*)—snake (*Morelia spilotes variegata*) cycle of a *Sarcocystis* species. The results of all these experiments yielded evidence that some animal species may be intermediate hosts for more than one *Sarcocystis* species, and other animals may act as final hosts also for several species.

The investigation of the endogenous development of some *Sarcocystis* species in the gut wall of the final host, and the attempts to transmit the sarcosporidian sporocysts to the respective final and intermediate hosts yielded rather unexpected results. Neither was it possible to demonstrate schizogonic stages of a *Sarcocystis* species of grackles in cell cultures (Fayer, 1970, 1972) nor could these stages be

* This paper is dedicated to Professor Dr. G. Piekarski on the anniversary of his 65th year.

found in the gut wall of cats infected with *Sarcocystis* species of cattle and sheep (Heydorn, Rommel, 1972b; Vershinin, 1973; Mehlhorn, Scholtyseck, 1974), nor in the gut wall of dogs infected with parasites of cattle (Heydorn, Rommel, 1972a; Fayer, 1974). On the other hand all investigators observed gamogonic and sporogonic stages as well as fully sporulated oocysts in the wall of the whole small intestine. The organisms were situated subepithelially in the lamina propria of the villi and were especially numerous in the ileum. So far the existence of microgamonts and microgametes could only be proved in cell cultures (Fayer, 1972).

The excretion of sarcosporidian sporocysts in the faeces of the final hosts for a period of six weeks is unusually long as compared to other *Isospora* species. The sporocysts excreted by cats and dogs were not infective to other cats and dogs (Fischle, 1973; Rommel *et al.*, 1974; Fayer, 1974). This proves that the oral ingestion of cysts from muscles of intermediate hosts is essential for the production of sporocysts in the final hosts.

After the finding of the coccidian nature of the sarcosporidia and the identification of their sporocysts in the faeces of the final hosts, it became possible to investigate their development in the intermediate hosts. Fayer and Johnson (1973, 1974) were the first to describe the development of the sarcosporidia of cattle in calves following oral infections with sporocysts from the faeces of dogs. Besides a remarkable pathogenicity of the parasites for calves, they noticed from day 20 to day 33 p. i. multiplying asexual stages (merogony)[1] predominantly within endothelial cells of various internal organs. Later in the muscles they found cysts which on the 54th day p.i. contained already the infective stages (merozoites) besides metrocytes.

In similar experiments Gestrich *et al.* (1975a) compared the development of sarcosporidia in calves following the oral application of sporocysts from the faeces of the three final hosts cat, dog and man. As a result of these experiments it was possible to distinguish between three morphologically different types of cysts in the muscles of the calves infected with the sporocysts from the faeces of dog, cat or man (Heydorn *et al.*, 1974, 1975a, b; Gestrich *et al.*, 1975a, b; Mehlhorn *et al.*, 1975a, b).

Corresponding preliminary investigations of the development of the sarcosporidia of sheep confirmed the suggestion that also the sporocysts of the sarcosporidia of sheep excreted by two different final hosts, dogs and cats, are developmental stages of two different *Sarcocystis* species (Gestrich *et al.*, 1974, 1975a; Munday, Rickard, 1974). In this series of experiments it was also possible to show that the sporocysts of *Sarcocystis* of cattle and sheep excreted by the same final host, the dog, are not identical species (Gestrich *et al.*, 1975a). Even though corresponding experiments with sporocysts excreted by cats following the ingestion of cysts from cattle and sheep have not yet been carried out, it can be assumed that also the sporocysts excreted by cats belong to two different species.

The results of the experiments of the last three years have revealed that two developmental stages of the same parasite have been associated with two different genera and thus have got different generic names. For the sarcosporidia these are the generic names *Isospora* and *Sarcocystis*. This fact is parallel to the unification of the genera *Eimeria* and *Coccidium* by Pfeiffer (1892).

1 Merogony = formation of merozoites (schizogony).

The genus *Isospora* was established by Schneider (1881). The definition given by him for this genus is relatively vague, describing only the oocysts with two sporocysts and not including details of the developmental cycle. According to the general opinion (Doflein, Reichenow, 1953; Pellérdy, 1974) the genus *Isospora* belongs to the family of the Eimeriidae (Minchin, 1903). Their common features are: life cycle in one host (=monoxenous), asexual multiplication within host cells (schizogony) followed by sexual differentiation (gamogony) still within the host cells, fertilization, oocyst formation, and finally sporogony inside the oocyst wall leading to the formation of sporocysts containing sporozoites. The number of sporocysts and sporozoites is characteristic for the genus.

This definition was shown to have little validity for some recently investigated members of the family Eimeriidae, like *Toxoplasma gondii* (Frenkel, 1973), small form of *Isospora bigemina* of the cat (Frenkel, Dubey, 1975), small form of *I. bigemina* and *I. rivolta* of the dog (Heydorn, 1973), *I. felis* and *I. rivolta* of the cat (Dubey, Frenkel, 1972; Frenkel, Dubey, 1972), large form of *I. bigemina* of the dog and the cat (Rommel *et al.*, 1972, 1974; Heydorn, Rommel, 1972a, b), *I. hominis* (Rommel, Heydorn, 1972a), and *Besnoitia besnoiti* (Peteshev *et al.*, 1974). The most important difference is that the above listed parasites have a two-host-life-cycle (=i.e. that they are heteroxenous).

According to our present knowledge the sarcosporidia, whose oocysts and sporocysts have been classified as *Isospora*, have some important differences in their life-cycles as compared to that of the genus *Isospora*. The most important differences are:

1. The obligatory two-host-cycle of the sarcosporidia (=heteroxenous).
2. Merogony (schizogony) in two phases leading to the formation of cysts in the intermediate host.
3. No asexual multiplication in the gut wall of the final host.
4. Gamogony and sporogony in a subepithelial position in the gut wall of the final host.

The developmental cycle of the sarcosporidia differs also in some essential points from the cycle of the newly established genus *Hammondia* (Frenkel, 1974; Frenkel, Dubey, 1975) which was classified as a member of the family Sarcocystidae:

1. By means of light microscope no metrocytes were observed during the formation of *Hammondia* cysts.
2. Merogony (schizogony) and gamogony take place within epithelial cells of the gut of the final host.
3. Oocysts are excreted unsporulated; sporogony typical outside of host.

By the finding of the life cycle of the sarcosporidia it became obvious that the sporocysts of various *Sarcocystis* species as well as the oocysts of completely different coccidian species of the dog and the cat have been named with the same name.

The scheme in Fig. 1 summarizes details of the present nomenclature of these organisms from the faeces of the cat, dog, and of man.

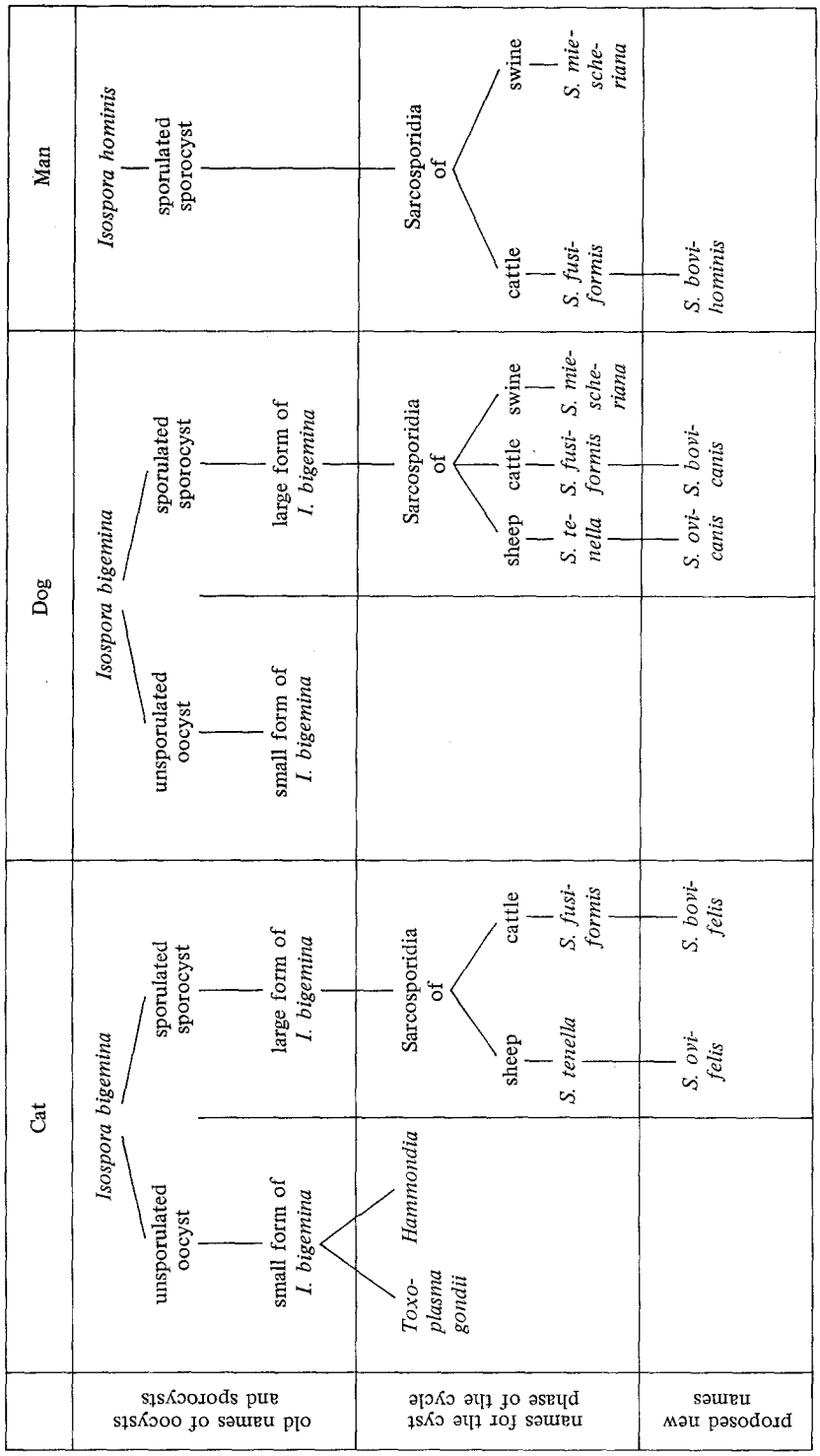

Fig. 1. The nomenclature of *Isospora bigemina* and *Isospora hominis*

The other developmental stage of the sarcosporidia, the cyst within the muscles of various animals, was first observed by Miescher (1843). Until 1882 the sarcosporidian cysts were termed as Miescher's tubes, Rainey's bodies or psorospermes. Because of the typical localization of the cyst within the muscles, Balbiani (1882) proposed the name sarcosporidia. In the same year, Lankester described the sarcosporidia of the pig as *Sarcocystis miescheri*, thus introducing the generic name *Sarcocystis*. Blanchard (1885) reviewed the literature comprehensively and for the first time attempted a classification. As criteria he used the localization of the cysts in the host and the structure of the cyst wall. He subdivided the sarcosporidia into two families, the Miescheridae and the Balbianidae.

He defined the Balbianidae as forming thin walled cysts in the connective tissue. As member of this family he listed only one species which was found in the mucosa of the large intestine of a kangaroo and which was macroscopically visible. Later in 1886, Railliet named the large cysts from the oesophagus of sheep also as *Balbiania gigantea*.

Sarcosporidia occurring in the striated muscles were classified as Miescheridae. Blanchard (1885) subdivided this family in two genera, the genus *Miescheria*, and the genus *Sarcocystis*. *Miescheria* had a thin and smooth cyst wall, while *Sarcocystis* had a thick striated one.

In the following years this classification was not recognized and the name *Sarcocystis* was generally used for all sarcosporidia. It was believed that the different structures of the cyst walls were different developmental stages of one cyst type. From this it was thought until today that each animal species is parasitized by only one sarcosporidian species and thus the morphologically different cysts found in one animal got one common name (*S. tenella* of sheep, *S. fusiformis* of cattle, *S. miescheriana* of pigs).

The results of the above reviewed investigations have shown that the three genera *Balbiania*, *Miescheria* and *Sarcocystis* characterize cysts of one parasitic genus and that the three generic names have to be considered as synonyms. The name *Sarcocystis* (Lankester, 1882) has priority.

Even though the sarcosporidian oocysts and sporocysts excreted by the final hosts are morphologically identical with those of the genus *Isospora*, we consider their separation from this genus to be necessary, because their life cycles are different. Considering our present knowledge we propose to retain the generic name *Sarcocystis* (Lankester, 1882) for all sarcosporidia.

The genus *Sarcocystis* should be defined as follows.

Genus *Sarcocystis* (Lankester, 1882)

Obligatory Two-Host-Cycle (= Heteroxenous)

In the Intermediate Host	*In the Final Host*
Merogony in two consecutive phases:	Gamogony and sporogony in the gut wall.
a) in internal organs	Oocysts with a very thin wall, without micropyle,
b) predominantly in muscles leading to cyst formation	containing two sporocysts; each with 4 sporozoites and a residual body, no Stieda-body

Due to the obligatory two-host-cycle of the sarcosporidia, and to the fact that the intermediate as well as the final hosts harbour more than one *Sarcocystis* species which are currently denoted by one name, it is required to introduce new species names. These new names should be formed by combining the names of the intermediate and the final hosts in this sequence. Since up to date we do not know a *Sarcocystis* species which parasitizes in two different genera of intermediate hosts, the generic name of the intermediate host concerned could be used.

The use of the generic name of the final host is however more difficult, since we know some *Sarcocystis* species parasitizing in more than one genus of final hosts (Heydorn *et al.*, 1975c). We propose that the generic name of the intermediate host is generally followed by the generic name of that final host which is epidemiologically the most important. Within the family of the Canidae, the domestic dog, for example, definitely plays a more important role in the epizootiology of the sarcosporidia of sheep and cattle than do wild carnivores. The same fact is valid for the domestic cat within the family of the Felidae, and man within the group of the primates. We propose to use in future a preliminary name for all sarcosporidia whose life cycles are not yet determined. The cysts in the muscles of an intermediate host should be called a *Sarcocystis* species of this host (e.g. *Sarcocystis* sp. of the horse) and the sporocysts from the faeces of a final host should be called the sporocysts of a *Sarcocystis* species of this host (e.g. the sporocysts of a *Sarcocystis* species of the lion). For those *Sarcocystis* species of cattle and sheep, whose life cycles have already been determined, we propose the following new species names:

Sarcocystis **(Lankester, 1882)**

1. *S. bovicanis* n. spec.

(syn. *S. fusiformis*, Railliet, 1897, pro parte;
S. blanchardi, Doflein, 1901, pro parte;
Miescheria cruzi, Hasselmann, 1926, pro parte;
Isospora bigemina, Stiles, 1891; Lühe 1906, pro parte).

Intermediate Host

Cattle (*Bos taurus*)

Cyst formation in muscles beginning about 30 days p.i.

Cyst wall: In light microscopy the wall of the mature cyst appears thin (less than 1 μ) and smooth. By means of electron microscopy a small number of 0,6–3,0 μ long, flattened protrusions without fibrils are visible following an irregular course along the surface of the cyst.

Final Host

Domestic dog (*Canis familiaris*);
Wolf (*Canis lupus*);
Coyote (*Canis latrans*);
Red fox (*Vulpes vulpes*).

Sporocysts from the faeces of the dog:
14.3–17.4 (16.3 ± 1.0) × 8.7–13.3 (10.8 ± 1.1) μ.

Prepatent period: 9–10 days.

Pathogenicity: Sporocysts of the dog highly pathogenic for calves.

2. *S. bovifelis* n. spec.[1]

(syn. *S. fusiformis*, Railliet, 1897, pro parte;
S. blanchardi, Doflein, 1901, pro parte;
Miescheria cruzi, Hasselmann, 1926, pro parte;
Isospora bigemina, Stiles 1891, Lühe 1906, pro parte).

Intermediate Host

Cattle (*Bos taurus*)

Cyst wall: In Formol fixed sections the wall of the mature cyst appears up to 5.4 μ thick and radially striated. By electron microscopy numerous, 3.8–5.5 (4.7) μ long, straight and commonly sloping protrusions containing 200–300 fibrils become visible.

Final Host

Domestic cat (*Felis catus*);
Feral cat (*Felis silvestris*).
Sporocysts from the faeces of domestic cats:
10.8–13.9 (12.5 ± 0.8) × 6.9–9.3 (7.8 ± 0.6) μ.
Prepatent period: 7–9 days.
Pathogenicity: Sporocysts not or only slightly pathogenic for calves.

3. *S. bovihominis* n. spec.

(syn. *S. fusiformis*, Railliet, 1897, pro parte;
S. blanchardi, Doflein, 1901, pro parte;
Miescheria cruzi, Hasselmann, 1926, pro parte;
Isospora hominis, Railliet, Lucet, 1891, pro parte).

Intermediate Host

Cattle (*Bos taurus*);
Cyst: predominantly spherical.
Cyst wall: In Formol fixed sections the wall of the mature cyst appears up to 6.9 μ thick and radially striated. By electron microscopy 4–7(5.9) μ long, straight and upright protrusions with numerous fibrils are visible.

Final Host

Man (*Homo sapiens*);
Rhesus monkey (*Macaca rhesus*);
Baboon (*Papio cynocephalus*).
Sporocysts from human stools:
13.1–17.0 (14.7 ± 0.8) × 7.7–10.8 (9.3 ± 0.5) μ.
Prepatent period: 9–10 days.
Pathogenicity: Sporocysts from human stools not or only slightly pathogenic for calves.

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1 This paper was discussed at the Round Table Discussion on "*Isospora, Toxoplasma, Sarcocystis* and Related Organisms" at the 2nd European Multicolloquy of Parasitology at Trogir/Yugoslavia from Sept. 1st to 6th, 1975. It was pointed out that according to International Nomenclature Rules *S. fusiformis* and *S. tenella* constitute a pro parte situation and the old names must be retained for two selected species. In this case we would prefer to denote the cat-cattle and cat-sheep species with the old names adding the new names in brackets: *S. fusiformis (bovifelis)* and *S. tenella (ovifelis)*.

4. *S. ovicanis* n. spec.
(syn. *S. tenella*, Railliet, 1886, pro parte;
Isospora bigemina, Stiles, 1891, Lühe, 1906, pro parte);
Intermediate Host
Domestic sheep (*Ovis aries*).
Cysts: Microscopic in size.
Cyst wall: In Formol fixed sections the wall of the mature cyst appears thick (up to 2.5 μ) and radially striated. By means of electron microscopy numerous, 2.0–3.5 (2.8) μ long, palisade-like protrusions without fibrils become visible.
Final Host
Domestic dog (*Canis familiaris*).
Sporocysts: 13.1–16.1 (14.8 ± 0.8) × 8.5–10.8 (9.9 ± 0.7) μ.
Prepatent period: 8–9 days.
Pathogenicity: Sporocysts highly pathogenic for lambs.

5. *S. ovifelis* n. spec.[1]
(syn. *S. tenella*, Railliet, 1886, pro parte.
Balbiania gigantea, Railliet, 1886;
Isospora bigemina, Stiles, 1891; Lühe, 1906, pro parte).
Intermediate Host
Domestic sheep (*Ovis aries*).
Cysts: Ovoid, up to 1.5 cm in size.
Cyst wall: With numerous cauliflower-like protrusions 1.0 –4.5 (3.5) μ long. Protrusions contain numerous fibrils. The parasitized host cell is enclosed by connective tissue forming a secondary cyst wall.
Final Host
Domestic cat (*Felis catus*).
Sporocysts: 10.8–13.9 (12.4 ± 0.8) × 7.7–9.3 (8.1 ± 0.5) μ.
Prepatent period: 11–14 days.
Pathogenicity: Sporocysts not pathogenic for lambs.

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