Bacteria and viruses were mostly excluded as the cause of numbers in the epithelium of the whole of the small intestine. Developmental stages of the parasite were found in varying posterior jejunum and in the ileum. Asexual and sexual lium, erosions and necrosis, especially in the medium and the mild crypt hyperplasia, fusion of the villi, metaplastic epithelium, atrophy of the villi in various degrees, including histology, virology and bacteriology. Histological examination revealed atrophy of the villi in various degrees, mild crypt hyperplasia, fusion of the villi, metaplastic epithelium, erosions and necrosis, especially in the medium and the posterior jejunum and in the ileum. Asexual and sexual developmental stages of the parasite were found in varying numbers in the epithelium of the whole of the small intestine. Bacteria and viruses were mostly excluded as the cause of diarrhoea, and it was concluded that *I. suis* was the primary pathogen inducing distinct changes and clinical symptoms of diarrhoea.

**Summary**

In order to evaluate the prevalence of *Isospora suis* in conventional piglet production in Germany, pooled faecal samples from 327 pig litters from 18 pig production units (20–320 sows each) were examined. At least 10 litters from each farm were investigated. *I. suis* was present on 83% of the farms and 42.5% of the litters, the infection rate being highest in the third week of age (48.2%). *I. suis* was found more frequently in samples of diarrhoea than in firm faeces (49.2% compared to 22.2%). Twenty naturally infected piglets from six of these farms underwent examination post mortem, including histology, virology and bacteriology. Histological examination revealed atrophy of the villi in various degrees, mild crypt hyperplasia, fusion of the villi, metaplastic epithelium, erosions and necrosis, especially in the medium and the posterior jejunum and in the ileum. Asexual and sexual developmental stages of the parasite were found in varying numbers in the epithelium of the whole of the small intestine. Bacteria and viruses were mostly excluded as the cause of diarrhoea, and it was concluded that *I. suis* was the primary pathogen inducing distinct changes and clinical symptoms of diarrhoea.

**Introduction**

*Isospora suis* has been described as an important cause of diarrhoea in young suckling piglets in the USA, Canada and Denmark (Bergeland, 1977; Sanford and Josephson, 1981; Henriksen et al., 1989). Various studies have shown that the parasite is also common in German piglet production and that parasitological findings correlate with diarrhoea (Mathea, 1993; Otten et al., 1996; Ilieff, 1997; Meyer et al., 1999). However, these coccidia are often neglected as a primary pathogen since clinical findings are not specific and detection of oocysts can be difficult and is rarely attempted. Piglets with isosporosis develop diarrhoea of varying consistency, mostly at 7 to 15 days of age; overall depression and dehydration can occur. In particular, reduced weight gain and overall poor performance of infected animals are of economic importance, while death occurs only rarely (Sangster et al., 1978; Stuart et al., 1980; Sanford and Josephson, 1981; Lindsay, 1989; Driesen et al., 1993). The aim of the present study was to investigate whether field infections with *I. suis* are associated with pathomorphological changes in the gut that are related to the clinical symptoms of diarrhoea.
culturalis in blood agar with subsequent subcultivation on MacConkey agar and finally further differentiation on endo-
agar. Salmonella were enriched in Preuß liquid medium, and material was also transferred to liver bouillon to test for
clostridia. In positive cases clostridia were differentiated further by toxin typing with a Bio-X-Enterotoxaemia ELISA
kit (BioX, Brussels, Belgium). Using Bacillus subtilis as the test
organism a test for antibiotic residues (three-plate-test) was
carried out. Using a SlideX Rota-Kit 2 (Bio Mérieux SA, Lyon,
France) and, in parallel, cell culture (cell line MA-104), rectal
or colonic contents were tested for rotavirus. Freeze sections of
the caudal jejunum and duodenum were investigated with
direct immunofluorescence for the presence of transmissible
gastroenteritis (TGE) virus or epizootic virus diarrhea (EVD)
virus.
The \( \chi^2 \) test was applied to compare percentages; for low
numbers of cases, Fisher's exact test was used. Differences
were considered significant at \( P \leq 0.05 \).

Results
Coprocopical examinations in piglet production units
Isospora suis was found in 15 (83%) of the 18 units
investigated. In all, 42.5% of the 327 litters were positive
(Table 1). Prevalence was highest in pigs at 15–21 days of
age (48.2%). At the age of 5–14 days 40.1% of the litters
excreted oocysts; 35.7% of the litters at 22–28 days old were
positive. With regard to the farm size \( I. \) suis was found more
often in small and medium-sized herds than in large herds
(Table 1). Litters kept in farrowing units with straw bedding
had only 8.3% of the litters on mainly perforated floors
of the perforated floor area. While in units where 50% or
less of the floor area was perforated 51.3% of the litters shed
\( I. \) suis, only 8.3% of the litters on mainly perforated floors
did so (\( P \leq 0.001 \)).

Litters with diarrhoea (i.e. pasty or liquid faeces) were
significantly more often infected with \( I. \) suis (\( P \leq 0.001 \))
than those without. While 49.2% of the litters with diarrhoea
\( (n = 264) \) were Isospora-positive only 22% of
the litters without diarrhoea \( (n = 81) \) shed oocysts. Similarly,
litters from 10 farms where diarrhoea was considered to
be a herd problem had higher prevalence rates (53.3% of
246 litters) than those from other farms (9.9% of 81 litters)
\( (P \leq 0.001) \).

Strongyloides ransomi eggs were found in five samples
(1.5%), Eimeria oocysts in one (0.3%) of 327 litters; all six
samples were from one farm.

Examination of Isospora-positive piglets
Clinical and parasitological findings
Of the 20 piglets, 14 were 8–15 days old, 5 17–20 days, one
was older than 21 days. Ten animals were slightly depressed, one
was severely depressed and nine behaved normally. The nutritional
status was poor in 17 cases. Eight piglets were dehydrated.
Eighteen animals had diarrhoea (Fig. 1). Isospora was found in
11 faecal samples, nine of which were diarrhoeic. Diarrhoeic
samples which were negative for \( I. \) suis were mostly liquid
or watery, while the positive samples were of pasty or semi-liquid
consistency and yellow-grey or light yellow in colour. Oocyst
counts showed values of \( 10^5 \cdots 10^{10} \) ooc, being highest in samples
with pasty consistency and yellow-grey colour.

Macroscopical findings
At gross post-mortem examination 18 piglets showed diffuse
hyperaemia of the small intestinal wall with liquid, yellow
contents which in some cases contained mucus or small milk
curds. In one case the posterior part of the small intestine was
covered with a thick yellow-grey pseudo-membranous fibrin
layer; another animal showed small flakes of fibrin in the liquid
intestinal contents. The mesenteric lymph nodes were enlarged
in 13 cases; 19 animals had a well-filled stomach.

Microscopical findings (Fig. 2A-D)
Histological examination revealed atrophy of the villi in
different grades (often severe), especially in the medial and
caudal jejunum and in the ileum, accompanied by mild crypt
hyperplasia. The villi were reduced and frequently fused,
covered with metaplastic, flat to cubic epithelium or with focal
tochorial loss of epithelium or necrosis. Occasionally, the
superficial epithelium was covered with thin layers of fibrinous
threads, detritus, inflammatory cells and bacteria. One piglet
suffered from diphtheroid-necrotic enteritis. The lamina pro-
pria showed mild to moderate accumulation of mononuclear
cells as well as a moderate to high focal to multifocal
infiltration with neutrophilic and eosinophilic granulocytes.
Mild oedema was found in some cases, and in one it was
severe.

Table 1. Numbers of piglet production farms and percentages of
\( I. \) suis positive litters

| Sizes (numbers of sows) | Farms (n) | Litters (n) | Positive litters (%) |
|-------------------------|-----------|-------------|----------------------|
| Small (20–69)           | 6         | 73          | 39.7                 |
| Medium (75–130)         | 10        | 234         | 46.6                 |
| Large (252–320)         | 2         | 20          | 5.0                  |
| Total                   | 18        | 327         | 42.5                 |

Fig. 1. Diarrhoea, dehydration and emaciation during acute isosporosis in a suckling piglet.
Endogenous stages of *I. suis* could be found in the ileum and jejunum, and in one case also in the caecum and colon. The medial (93%) and caudal (85%) jejunum and the ileum (75%) were affected significantly (\(P \leq 0.05\)) more often than the cranial jejunum (33%). The parasitic stages, which were surrounded by a parasitophorous vacuole, were mainly found in the epithelium of the distal ends of the villi; at high levels of infection parasites were also found at the base of the villi and occasionally in the epithelium of the crypts. In one case few goblet cells were also infected. In areas with extensive epithelial damage, few or no parasites were found. In all, more asexual (84.8%) than sexual (15.2%) stages were found in the epithelium. Of the nine piglets which had been negative at coproscopy, three harboured exclusively asexual stages, three mainly asexual stages, and three were only weakly infected. The piglets that had been coproscopically positive for *Isospora* all contained sexual stages in their epithelium.

**Differential diagnostic findings**

Sixteen out of 20 *I. suis*-positive piglets had infections with one or more bacterial or viral agents. *E. coli* could be isolated from 12 animals, with three isolates growing with haemolysis on blood agar (*E. coli* vs. h). Five out of 10 samples tested for *C. perfringens* type A were positive. Two bacteriologically negative animals were positive for antibiotic residues. Rotavirus was found in one case, while neither TGE nor EDV viruses were found in the 19 animals examined. Neither *S. ransoni* nor *Cryptosporidium parvum* were found.

**Discussion**

In concordance with Otten et al. (1996) and Meyer et al. (1999) the results of the present study show that in Germany *I. suis* is widely distributed amongst young suckling piglets and that infection is associated with diarrhoea. In other studies, coccidia were also found in 60–80% of the farms investigated (Driesen et al., 1993; Eysker et al., 1994; Ilieff, 1997). The average litter infection rate lies in the range of those (36.3%) found in the Netherlands by Eysker et al. (1994). Higher (cumulative) infection rates of 53.8–62.2% were found when litters were examined several times in weekly intervals (Eysker et al., 1994; Otten et al., 1996; Meyer et al., 1999). We found that the highest rates of infection of the litters was in the third week of age, which is in concordance with Otten et al. (1996). In contrast, Meyer et al. (1999) found that in large piglet production units with good management the prevalence increased until the fourth week, which Daugschies et al. (1999) put down to slower spread of the infection on farms with good hygiene management. According to Lindsay et al. (1992) and Otten et al. (1996) isosporosis can occur on any farm, independently of the size or management. However, we found that *I. suis* was regularly found in small to medium-sized units and on farms with straw bedding. Additionally, the
prevalence was negatively correlated with the percentage of perforated floor areas, perhaps due to less contact between the piglets and their faeces, which is in concordance with the results of other authors (Sayd and Kawazone, 1996; Meyer et al., 1999). Sangster et al. (1978) speculated that isosporosis is more common in units with straw bedding due to a poor hygienic status. Meyer et al. (1999), however, frequently found the parasite also in large, well-managed piglet production units, while above-average hygiene measures in a nucleus herd were associated with low infection rates. Contaminated farrowing units are probably the most important source of infection of the piglets (Lindsay, 1989), and consequently hygiene is of utmost importance to lower the infection pressure; however, even after thorough cleaning and disinfection few oocysts can remain which are sufficient for the spread of infection (Christensen and Henrikсен, 1994).

The necropsied piglets mostly displayed signs of disease described in the literature. Only two animals had no diarrhoea despite oocyst excretion; however, the course of disease can also be subclinical (Matuschka and Heydorn, 1980; Stuart et al., 1982; Otten et al., 1996; Meyer et al., 1999). As previously described (Otten et al., 1996; Meyer et al., 1999) oocysts were found most frequently in faecal samples of pasty consistency and yellow-grey colour. This should be taken into consideration for diagnostic sampling; however, it has to be kept in mind that the ingestion of pre-starter feed or turf can influence the colour of the faeces.

At necropsy we found that, in concordance with other authors (Sangster et al., 1978; Eustis and Nelson, 1981), in cases of isosporosis macroscopic alteration is often only discrete and obvious pseudomembranous fibrinous layers are rare. Histological lesions were found mainly in the medial and caudal jejunum and in the ileum, and in these sections parasite stages in the epithelium were most common. We therefore recommend that several tissue samples be removed from these areas of the small intestines. The microscopic alterations of the intestinal mucosa were also described by other authors for piglets with natural (Eustis and Nelson, 1981; Vitovec and Koudela, 1987) or experimental (Matuschka and Heydorn, 1980) isosporosis. In cases of field infections more asexual than sexual stages were found in the epithelium (Sanford and Josephson, 1981; Chae et al., 1998), which is in agreement with our findings. Piglets infected primarily with asexual stages at necropsy displayed the most prominent pathohistological changes of the intestinal mucosa, as described by Stuart et al. (1980) and Robinson et al. (1983), and the stages can be considered to be the more pathogenic. The position of the endogenous stages in the epithelium was identical to previous observations (Lindsay et al., 1980; Matuschka and Heydorn, 1980; Harleman and Meyer, 1984); occasionally the large intestines are affected without significant histological alterations (Sangster et al., 1978; Sanford and Josephson, 1981; Harleman and Meyer, 1984). Several animals harboured only few parasites in the different intestinal sections despite distinct mucosal alterations, as previously described by Current (1987) and Lindsay et al. (1999). According to Stuart et al. (1982) the degree and distribution of the Isospora-induced alterations depend on the age of the piglet and the infection dose. Since in cases of field infections time and dose of infection are unknown, we could not correlate the pathohistological changes to the infection rate of the epithelium. However, it could be demonstrated that infection of the intestinal epithelium with coccidia is unambiguously correlated with pathohistological changes of varying degrees. Isosporosis was diagnosed more often by histology than by coproscopy only, so that the histological examination of piglets sacrificed for diagnostic necropsy should be part of Isospora diagnosis.

In the cases we investigated other enteropathogens were probably of only minor importance as causes of diarrhoea. Faecal examination of the litters showed that S. ransomi and Elmeria spp. occurred only rarely in suckling pigs and, as is the case for Cryptosporidium, were negligible as causative agents for diarrhoea. Similarly, viruses were found only rarely in our investigations. Coronavirus, which cause TGE and EVD, could not be isolated. In general, these agents seem to have declined in importance since PRCV (porcine respiratory coronavirus) was found in Europe (Paul et al., 1994) and are more common in weaners (Heinritz et al., 1990). Rotavirus was found in a 20-day-old piglet; however, this animal did not display more distinct lesions of the small intestine than those with pure Isospora infections as described by some authors (Eustis and Nelson, 1981; Vitovec and Koudela, 1987), which is probably due to the age of the animal. Pure rotavirus infections often do not cause any symptoms due to the ubiquity of the virus and the immune protection of the piglets (Waldmann and Plonait, 1997).

Bacteriological testing excluded Salmonella infections. C. perfringens type A can lead to mild villous atrophy, but it can also be found in the faeces of healthy animals (Waldmann and Plonait, 1997). C. perfringens type A was found in five out of 10 animals examined. A synergistic effect of these bacteria with I. suis, as described by Nabuurs et al. (1983) for rotaviruses, cannot be excluded and requires further investigations. E. coli was found in 12 animals. Enterotoxig E. coli (ETEC) are amongst the most important causes for diarrhoea in suckling piglets and weaners; however, the cause for diarrhoea is hyperecretions with little or no mucosal lesions of the mucosa (Waldmann and Plonait, 1997). Only three of the 12 E. coli isolates were haemolytic and have to be considered as pathogenic for piglets. In previous works ETEC were also only rarely found in Isospora-infected piglets (Ilief, 1997; Chae et al., 1998). The rare occurrence of pathogenic E. coli in our study is probably due to vaccination of the sows.

While Driesen et al. (1993) and Ilief (1997) diagnosed I. suis infections mainly as monoinfections, Meyer et al. (1999) showed that isosporosis is frequently associated with E. coli infections. Bergeland (1977) hypothesized that necrotic enteritis in the course of isosporosis is due to multicause infections with viruses and bacteria. We only found necrotic enteritis in one case of isosporosis with concurrent infection with C. perfringens type A. It can be assumed that secondary pathogens can exacerbate an Isospora infection, and that the infection rate of the epithelium with parasite stages causing primary damage plays a crucial role for the course of the disease. Competing infectious agents make diagnosis more difficult and may be misinterpreted as primary causes of diarrhoea (Greve, 1985; Lindsay et al., 1992), so that a complete diagnosis even after isolation of one enteropathogen is important (Chae et al., 1998).

The importance of I. suis as a primary pathogen has been demonstrated by several experimental studies (Stuart et al., 1980; Robinson et al., 1983; Harleman and Meyer, 1984; Vitovec and Koudela, 1990) and is substantiated by the present work. The results of coproscopy and necropsy make it clear that under management practices common in Germany I. suis

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infections are correlated with diarrhea. Higgins (1999) hypothesized that in the United Kingdom isosporosis is commonly overlooked, and in cases of diarrhea and poor performance of suckling piglets Isospora-directed diagnosis should be strongly considered. The increasing awareness of *I. suis* as an important enteropathogen in suckling piglets led to the recommendation of Martineau and Del Castillo (1999) to use toltrazuril (Baycox®, Bayer) for ‘diagnostic therapy’ in cases where clinical and epidemiological findings are characteristic. The present investigation substantiates the impression that *I. suis* is also a primary cause of diarrhea under the conditions of piglet production in Germany.

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