Lameness in piglets

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Abstract

Lameness in suckling piglets is a major problem in farrowing enterprises. Apart from animal suffering, lameness contributes to losses in form of dead piglets, decreased growth, and increased use of antibiotics and manual labour. The present study focused on risks for development of lameness in different housing systems.

In the first study, lameness in piglets up to nine of age was studied in a research station herd for four years. 9,411 piglets were born alive, out of which 9.8% were treated for lameness during suckling. Lameness was observed in about every second litter and around 75% of the treatments against lameness were effectuated in piglets less than 3 weeks of age. The incidence risk of lameness decreased from 2.7% during the first week of life to 0.3% after weaning. Litters with 12 or more piglets had a higher incidence of lameness, but no difference between the sexes was seen.

In the second study, the implications of skin lesions in young piglets and the protective role of maternal immunity towards development of arthritis was estimated. Skin lesions were present already on day 3. They increased in magnitude until day 10 and thereafter declined. They were generally bilateral and most commonly observed as abrasions over the carpal joints. Hocks, face, abdomen and tails were affected in a similar way, but at lower magnitudes. Sole bruisings were observed in 87% of the piglets at the third day of life, and moderate to severe lesions dominated until day 10. Thereafter the incidence decreased, indicating healing with time. Still, 39% of the piglets were affected at day 17.

In the third study, the overall incidence of lameness was decreased and lameness was only diagnosed in every fourth litter in a system with deep litter peat, compared to in every second litter in the systems with solid concrete floor.

Still it must be remember that concrete floor system facilitate hygienic measurements in a technical way. Therefore, the influence of floor type and bedding intensity on the incidence and severity of foot and skin lesions and development of arthritis in young piglets was monitored in identical farrowing pens in the fourth study. Floor maintenance decreased the significance of abrasions and sole bruisings, and also reduced the incidence of lameness. Also doubling the amount of chopped straw prevented lameness to some extent.

Keywords: piglets, lameness, abrasion, microbes, farrowing pen, floor, peat

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Till Dario, Ivana och Snjezana

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Zoric, M., Stern, S., Lundeheim, N. and Wallgren, P. (2003). Four-year study of lameness in piglets at a research station. *Vet Rec* 153, 323-328.

II Zoric, M., Sjölund, M., Persson, M., Nilsson, E., Lundeheim, N. and Wallgren, P. (2004). Lameness in piglets. Abrasions in nursing piglets and transfer of protection towards infections with Streptococci from sow to offspring. *J Vet Med B* 51, 278-284.

III Zoric, M., Nilsson, E., Mattsson, S., Lundeheim, N. and Wallgren, P. (2008). Abrasions and lameness in piglets born in different farrowing systems with different types of floor. *Acta Vet Scand* 50:37. Electronic publication; 9 pages.

IV Zoric, M., Nilsson, E., Lundeheim, N. and Wallgren, P. (2008). Incidence of lameness and abrasions in piglets in identical farrowing pens with four different types of floor. *Vet Rec* Accepted for publication.

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Abbreviations

E. coli	*Escherichia coli*
ELISA	Enzyme – Linked Immuno Sorbent Assay
LR	Landrace
NVI	National Veterinary Institute
SAS	Statistical Analysis System
WL	White Large

Introduction

Locomotory disorders are one of the most relevant health problems in pig production world wide. Beside the disturbances of animal welfare the financial losses are important especially due to prolonged fattening period, losses in suckling pigs, reproductive failure in sows and boars and early culling of fattening or breeding pigs (Wallgren 2000; Waldmann 2004). Lameness is a term that is used to designate a broad spectrum of clinical signs of locomotor disorders ranging from slightly abnormal gait to conditions were a limb does not bear weight at all. In its extreme form lameness includes total paralysis (Hill et al., 1996). Causes of lameness can be broadly classified as genetic, congenital, physical injuries and infection.

The most common conditions affecting the locomotor system of preweaning pigs are splayleg, polyarthritis and skin abrasions.

Splayleg

The major congenital cause of lameness is splayleg in suckling piglets. This condition is complex and not fully understood. The condition has been associated with low birth weight, slippery floors, *Fusarium* toxicity, choline or methoionine deficiency in sow diets as well to short gestation lengths (Ward 1978). With respect to breed, WL & LR have been mentioned. Some researchers describe muscle hypoplasia as the cause of the clinical signs, but myofibrillar hypoplasia is normal in all newborn pigs. Splayleg is caused by a reduction of the axonal diameter and myelin sheath thickness of the fiber that innervate the hindlimb adductors (Szalay et al., 2001).

Clinically, pigs show extreme abduction of the limbs with an inability to stand. Splayleg affects the hindlimb adductors and in sever cases the forelegs are also involved (Szalay et al., 2001). Typically every second affected pig die due to starvation and overlying, because the pigs have difficulties in reaching the udder, retaining hold of the nipple, competing with their littermates and moving out of the sows lying space. Affected pigs can be kept alive if they are fed artificially including colostrums, nursed well and have their limbs taped in a natural standing pose. Pigs that survive the first week of life will recover completely (Dewey 2006).

Polyarthritis

Lameness in piglets is commonly associated with arthritis, but the incidence is not correlated with either herd size or rearing strategy (Christensen 1996; Josiassen and Christensen 1999). The condition may have various outcomes; septicaemic polyarthritis have been reported to affect 3.3% of the liveborn piglets before they are four days old and to have a mortality rate of 1.4% (Nielsen et al., 1975a); infectious arthritis affecting single joints have been most commonly observed in piglets less than three weeks old (Dewey 2006).

Haemolityc streptococci is the dominating agent associated with polyarthritis, but *Staphylococcus* species & *Escherichia coli* are also commonly causative agents (Nielsen et al., 1975b; Smith and Mitchell 1976; Jones 1976). Any bacteria that enter the bloodstream may induce arthritis (Windsor 1978), particularly if the piglets have consumed too little colostrum. The dominance of the *Streptococcus* species is associated with the common presence of group C and group L streptococci in the tonsils, throat, milk and vaginal secretions of sow (Hare et al., 1942; Shuman et al., 1969; McDonald and McDonald 1975; Jones 1976), indicating that the dam is an important source of the infections (Field et al. 1954; Elliot et al., 1966; Christensen 1996; Higgins and Gottschalk 2006).

Common sites of invasion include skin wounds, or when the sow is the source of infection, the tonsils and/or pharynx (Helms 1962, Sanford and Tilker 1982, Clifton-Hadley 1983). Injuries induced by surgery or teeth clipping may also introduce bacteria (Riising et al., 1976; Becker 1992). Further, higher incidences of arthritis have been reported among piglets that have been castrated, teeth clipped or tail docked, and during the winter (Nielsen et al., 1975b; Riising et al., 1976; Smith and Mitchell 1976).

The association between arthritis and *Streptococcus* species declines as the piglets age. Among weaned piglets, arthritis is typically associated with microbes such as *Erysipelothrix rhusiopathiae*, *Haemophilus parasuis*, *Mycoplasma hyorhinis* or possibly *Mycoplasma hyosinoviae* (Smith and Morgan 1997; Dewey 2006); the last agent is, however, more commonly associated with arthritis during the fattening period.

Skin Abrasions

Abrasions, wounds and necrosis in the skin or on the hooves and accessory digits, are very common in newborn piglets, and can almost be classified as "normal" in most pig farms (Penny et al., 1971; Svendsen et al., 1979; Valton 1995). Foot and skin lesions cause discomfort to the piglets and also provides an entry for infections, which may result in lameness (Penny et al., 1971; Phillips et al., 1995).

During the first week of life the piglets spend most of their time lying in the nest (Zhou et al., 1995), and it is obvious that the immediate environment of the piglets plays a primary etiological role in the appearance and development of leg injuries in suckling piglets. However, the provoking factors may vary between herds. They include the design of the farrowing pen, the construction and condition of the floor surface as well as type and amount of bedding material used (Smith and Mitchell 1976; Hoy and Ziron 1998; Smith 2003; Tuyttens 2005).

Lameness in sucking piglets is observed in about every second litter and around 75% of the treatments against lameness are effectuated in very young piglets, less than 3 weeks of age (Egeli et al., 2001; Zoric et al., 2003; Zoric et al., 2004). The quality of the floor is essential to the welfare of the piglets because abrasions are often recorded in newborn piglets, and such lesions may lead to arthritis and lameness. Joint swelling and lameness are the most obvious and persistent clinical signs of lameness in piglets. Elevated temperatures, lassitude, roughened hair coat and inappetence may also be noted. Early lesions consist of periarticular edema; swollen, hyperemic synovial membranes; and turbid synovial fluid. Apart from animal suffering, lameness contributes to losses in form of dead piglets, decreased growth, and increased use of antibiotics and to manual labour.

Aims of the present study

The general objective of this thesis was to increase the understanding concerning the risks for development of lameness in piglets. This task was divided into five specific aims;

> to analyse the incidence of lameness in piglets and to determine its influence on productivity;
>
> to estimate the current prevalence and distribution of abresions in nursing piglets aged less than three weeks;
>
> to evaluate the protective role of maternal immunity towards development of arthritis;
>
> to compare different farrowing systems with respect to the incidence and severity of abrasions, as well as, on the incidence of lameness, in nursing piglets in different farrowing pen systems;
>
> to monitor the influence of floor type and bedding intensity on the incidence and severity of foot and skin lesions and development of arthritis in young piglets in identical farrowing systems.

Comments on Material and Methods

In order to clarify the choice and use of materials and methods used in the studies of this thesis, a brief presentation is given here. Additional details are presented in the material and methods sections of the individual papers.

Herd, animals and management routines

In paper **I**, the study was carried out at the research station at Funbo-Lövsta, Swedih University of Agricultural Sciences. The farrow-to-finish herd comprised 110 sows (mainly purebred Yorksire) and had been established for 20 years. It was free from diseases listed by IOE (International office of epizootics), and several other diseases.

While the sows were pregnant, they were housed in a deep-litter system in groups of 16, but fed individually. Two weeks before farrowing, they were transferred to a cleaned farrowing unit with 16 pens, each 11 m^2 in area and bedded with straw.

The field studies (papers **II**, **III**, **IV**) were performed in conventional farow to finish herds with Yorkshir x Landrace sows in production (175; 250 and 180 sows, respectively). In all herds the pregnant sows were group housed in a deep-litter straw system, but fed individually. Three to four days before expected farrowing, the sows were transferred to a previously emptied and cleaned farrowing unit with individual farrowing pens; paper **II** = 18 farrowing pens with solid concrete floor embedded with straw and chip (7.2 m^2); paper **III** = 3 units with different types of farrowing pens in the herd: an old housing system with 21 farrowing pens (5.9 m^2) with concrete floor embedded with chopped straw, a new housing system with 24 farrowing pens (7.4 m^2) with concrete floor with dunging area embedded with chopped straw, and a deep litter peat housing system with 40 farrowing pens (5.6 m^2); paper **IV** = four identical farrowing units with 15 identical farrowing pens (7.0 m^2) with concrete floor embedded with 1 kg chopped straw per sow and 1 hg per piglet and day. Nothing was changed in the management of the four identical farrowing units, but four experimental groups were created: Group I – control, Group II - the amount of bedding was doubled and the surface of the floor was altered in two of them, Group III - Piglet Floor®, Flowcrete Sweden AB, Perstorp, Sweden and Group IV - Thorocrete SL®, Växa Halland, Sweden.

The male piglets were castrated at two to five days of age and at the same time all the piglets received an intramuscular injection of 200 mg iron as iron dextran. The piglets were given a second iron injection ten days later. The piglets were offered a commercial creep feed without antibiotics from the age of ten days.

Records of diseases and medical treatments were kept for each sow and piglet. The veterinarian of the herd had given instructions for diagnosing and decided what treatment was to be given, but the staff of the herd generally effectuated them.

Study population

All of the 9,411 piglets born alive during a period of four years were studied (paper **I**). After the sows had farrowed, each piglet was weighed and numbered. Their navels were disinfected, their canine teeth were filed and, to prevent abrasions, canvas was glued to their carpal joints. The piglets were also weighed when they were aged three, five (at weaning) and nine weeks. Data from the piglets were studied with respect to arthritis as was diagnosed and medicinally treated.

The field studies included: one farrowing batch of 17 sows and their offspring (n = 175, paper **II**); one farrowing batch within each of the 3 farrowing systems: 37 sows (11, 11, 15) and their offspring, 390 (n = 120, n = 117, n = 153, paper **III**); three consecutive farrowing batches in each of four units: 93 sows (28, 19, 22, 24) and their offspring, 1,073 (n = 335, n = 210, n = 243, n = 285, paper **IV**). Piglets were individually examined day 3, day 10 and day 17 with respect to presence of skin wound and abrasion, and until the age of 32 days (paper **IV**) and 7 weeks (papers **II**, **III**) with respect to development of lameness.

Definition of the term arthritis

Lameness and/or visibly swollen joint(s) were defined as arthritis. The technical staff made the diagnosis on the basis of instructions from the herds veterinarian. As soon as arthritis was diagnosed, antibiotics were administered.

Examination of feet, limb and skin in piglets

The piglets were restrained and examined (papers **II**, **III**, **IV**) for presence of skin lesions of the carpus, hock, abdomen and teats, face and tail. Further, castration wounds were inspected and feet were examined with to respect to presence of sole bruising. All examinations were performed by one and the same veterinarian. The severity of the lesions was scored as 0, 1, 2 or 3 according to Table 1. In addition, the severity of the lesions was correlated to the sex of the piglet.

Table 1. *The severity of the lesions recorded at day 3, day 10, day 17 was scored as 0, 1, 2 or 3 defined as shown below*

Score	Skin lesions	Sole bruising*/ Sole erosion	Castration wounds
0 - No lesion	-	-	-
1 - Mild	Hairless patches or loss of hair and mild hyperkeratosis	Small part of the volar surface of digit affected	Mild inflammation, eczema or oedema
2 - Moderate	Skin abrasions *i.e.* skin on worn away	Less than half of the volar surface of the digit affected	Clinical signs of inflammation, swelling, redness, localized warmth
3 - Severe	Skin wounds. Spots of induration or scab that is a hard mass mainly of dried blood.	More than half of the volar surface digit affected or sole erosion, loss of horny tissue.	Inflamed castration wounds with purulence. Smelly wound. Abscess.

* Sole bruising was defined as congestion and bruising of the solar corium presenting as a dark red pigmentation on the volar surface of the foot.

Necropsies, bacteria cultivations and monitoring, antimicrobial resistance

Occasional lame piglets were culled instead of medically treated (papers **II**, **III**, **IV**). To exclude sprains, these piglets had to be lame and/ or express visibly swollen joint(s) for 2 days before the diagnosis was given. They bodies were stored at -20˚C until necropsied when all limb joints were examined.

Samples for bacteriology were collected with sterile cotton swabs from up to 3 affected joints and from a normal joint from each pig at necropsy (papers **II**, **III**, **IV**). The samples were spread directly to blood agar (blood agar base No. 2; LabM, Salford, England + 5% horse blood) and bromcresol purple-lactose agar (NVI art No.341200). The plates were incubated at 37°C and read after 18 and 48 hours.

Isolates of staphylococci and streptococci species were typed with methods used at the Bacteriological diagnostic laboratory at the National Veterinary Institute (NVI) and tested with respect to antimicrobial resistance towards penicillin, ampicillin, ceftiofur, spiramycin, neomycin, gentamycin, streptomycin, trimethoprim/sulfa, enrofloxacin, oxytetracycline, florfenicol and oxacillin (VetMIC™ Large Animal, NVI; (papers **III**, **IV**).

Blood samplings

In paper **II**, blood samples were obtained from sows by jugular vein punctures and from piglets by anterior vena cava vein punctures using evacuated glass tubes without additive. Serum was collected from the dams (n = 8) one month before farrowing, at the week of farrowing and 3 weeks after farrowing. Serum was also collected from selected piglets (n = 48, six from each of the 8 litters) once every week from birth to the age of 7 weeks.

Preparation of antigen from *Streptococcus dysgalactiae* subsp. *equisimilis* and detection of antibodies to *Streptococcus dysgalactiae* subsp. *equisimilis*

For preparation of antigen, a field isolate of *Streptococcus dysgalactiae* subsp. *equisimilis* was cultured and ultrasonicated. Serum antibodies to *Streptococcus dysgalactiae* subsp. *equisimilis* were detected by an indirect ELISA system using this antigen as described in detail in paper **II**.

Statistical analyses

In the studies included in this thesis, only the first time lameness was diagnosed for an individual piglet, was included in the statistical analyses. Thus recurrence of arthritis was ignored. In paper **I**, the prevalence of lameness was analysed using the GENMOD procedure (binomial distribution; SAS Inst. Inc., Cary, NC), according to a statistical model including the fixed effects of sex (two classes), birth year (four classes), birth month (12 classes), parity (five classes; 1 to 4 and ≥5), number of liveborn piglets in the litter (nine classes, eight to 16 livebron piglets) and weight at birth (11 classes; <1.1 kg, 1.1 to 1.9 kg, >1.9 kg). The identity of the litter was specified as "subject".

The prevalence of arthritis was also analysed monofactorially. These analyses were carried out in relation to age (papers **I**, **II**, **III**, **IV**), sex (papers **I**, **II**, **III**, **IV**), weight at birth (paper **I**), parity (paper **I**) litter size (papers **I**, **II**, **III**), health status of dam (papers **I**, **II**, **III**), age at iron injection and calendar month (paper **I**), by using *t* tests and chi-squared tests (SAS Inst. Inc., Cary, NC).

The weekly risk incidence for treatment due to lameness was calculated as the number of piglets affected with arthritis during the actual period divided by the number of live piglets previously not affected by lameness at the beginning of the period (papers **I**, **II**, **III**, **IV**).

The proportional mortality among piglets was analysed in relation to health status of dam (treated against mastitis or healthy sow). The number of piglets that died during the period studied was divided with the number of live piglets at the beginning of the period (paper **I**).

The difference in median level of antibodies to *Streptococcus dysgalactiae* subsp. *equisimilis* between consecutive blood sampling occasions were analysed in relation to age & sex of piglets and in relation to farrowing of the sows (paper **II**).

In paper **II**, the association between skin lesions scores at different sites within day at three different occasions and the association between skin lesions scores, within site, between age in 48 piglets with know identity was investigated by using the Spearman rank correlations test (STATISTICA Version 6, StatSoft. Inc., Tulsa, OK). The association was considered to be significant if the Spearman rank correlation coefficient was greater than the coefficient for a probability value of $p \leq 0.05$ for a two-sided test.

The prevalence of each lesion on each day (3, 10, 17) was defined as the number of piglets with that lesion divided with the number of piglets examined that day (papers **II**, **III**, **IV**). The prevalence of foot and skin lesions were further analysed in relation to age & sex of the piglet and in relation to the health status of dam (papers **II**, **III**).

In papers **III** and **IV**, an average score for each litter - sex - age was calculated for each lesion type. These averages were analysed using analyses of variance (PROC MIXED; SAS Inst. Inc., Cary, NC) according to statistical models including the fixed effects of floor type, sex, age and interactions between group and day. In the statistical model, also the random effect of litter nested within floor type was included. Pairwise tests of significance between least-squares means were performed using t-test.

Results and Discussion

Relationship with age and risk incidence of lameness

Lameness is associated with many factors and cannot usually be blamed by only one cause. Housing appears to be an important factor influencing the level of lameness when individual herds have been scrutinised (Barnett et al., 2001; Smith 2003; Dewey 2006).

Lameness in piglets up to nine weeks of age was studied in the research station herd for four years (paper **I**); 9,411 piglets were born alive, out of which 9.8% were treated for lameness. Around 75% of all cases were observed in piglets less than three weeks of age and the incidence risk for lameness decreased from 2.7% during the first week of life to 0.3% after weaning (Figure 1).

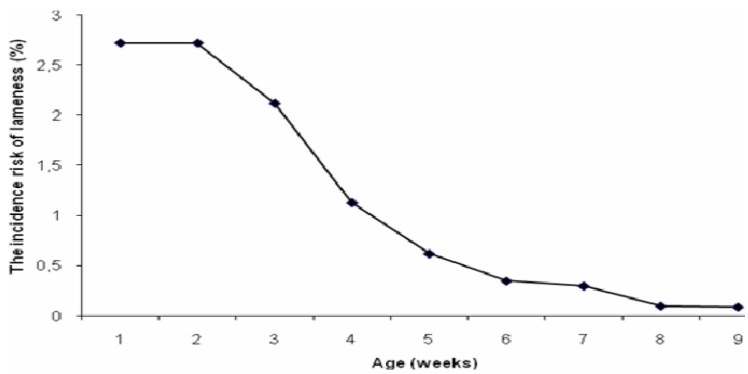

Figure 1. Mean incidence risk of piglets of different ages being treated for lameness during the first nine weeks of life.

In the second study (paper **II**), lameness was diagnosed in 10.9% of the piglets in a group of 175 newborn piglets, in the housing system with the solid concrete floor embedded with straw and chip. About every second litter was affected and around 75% of these diagnoses took place during the first three weeks of life. The risk incidence of lameness decreased from 3.6% during the first week of life to around 1% from living week 4 onwards.

In a herd with three different farrowing systems, 390 piglets were studied until the age of 7 weeks with respect to presence of lameness (paper **III**). The overall prevalence of lameness was highest in the system with a new solid concrete floor (9.4%) followed by the old solid concrete floor (7.5%). A lower ($p < 0.05$) incidence was seen in the system with deep litter peat (3.3%). Around 75% of the treatments for lameness were performed during first three weeks of life in the two farrowing systems with solid concrete floor. Lameness was diagnosed in about every second litter in these compared to in about every fourth litter in the system with deep litter peat.

In the fourth study (paper **IV**), the herd had four identical farrowing units with 15 identical farrowing pens. Nothing was changed in the management of the four identical farrowing units, but the surface of the floor was altered in two of them, and the amount of bedding was doubled in the third unit. In total 41 piglets were diagnosed as lame, corresponding to 3.8% of all live-born piglets (n = 1,073). Around 85% of these diagnoses took place during the first 3 weeks of life and the risk incidence of lameness decreased from 1.5% during the first week of life to 0.5% during the fourth week. The prevalence of lameness was highest in the control group (5.9%) and lowest in the group with repaired floors (2.9%; $p < 0.05$; Group III – Piglet Floor®; and 1.8%; $p < 0.01$; Group IV – Thorocrete SL®). Also doubling the amount of chopped straw prevented lameness to some extent (4.3%).

Between 75% **(**papers **I**, **II**, **III**) and 85% (paper **IV**) of the treatments for lameness were effectuated when the piglets were aged less than three weeks. Thereafter, the prevalence of treatments for arthritis and the incidence risk of developing lameness gradually decreased. This association with age may indicate an association with *Streptococcus* species, because this organism is commonly isolated from piglets aged one to three weeks (Higgins and Gottschalk 2006).

Relationship with sex, weight at birth and weight gain

In contrast to the results recorded by Nielsen and others (1975a), there was no difference in the incidence of arthritis between the sexes over the four years (barrows, 10.2%; gilts, 9.4%; paper **I**), suggesting that castration by itself may not predispose to development of arthritis provided that it is effectuated skillfully and under aseptic conditions.

A somewhat higher prevalence of lameness was recorded for heavy barrows and light gilts (paper **I**). However, these differences were not significant when assessed by chi-squared tests using 1,500 g as the limit for being considered light or heavy at birth. When heavy barrows were compared with heavy gilts (> 1,500 g) under this condition, they were more often ($p < 0.05$) treated for arthritis. Similar observations were made by Mouttotou and Green (1999), who found that piglets which developed sole bruising and sole erosions on the first day of life were significantly heavier than those which did not. The digits of heavier piglets carry a heavier load and may therefore more easily develop foot lesions.

Like other diseases (Young et al., 1959; Caldwell et al., 1961; Lundeheim 1986; Wallgren 2000; Johansen et al., 2004), lameness reduced the growth rate of the piglets. The piglets that were treated for arthritis grew 8% more slowly than those that were not treated. Within sex there was no difference between the mean weight at birth of piglets which were or were not subsequently treated for lameness (paper **I**). In contrast, the piglets treated for lameness expressed a retarded growth. At nine weeks of age barrows that had been treated for arthritis weighed 1.5 kg less than other barrows ($p < 0.001$). The corresponding difference for gilts was 1.3 kg ($p < 0.001$).

Mortality

The number of liveborn piglets and the number of piglets that died during the first nine weeks of life were divided with respect to sex and whether they were treated for lameness or not (paper **I**). The mortality during the first three days of life was high, in agreement with the observation by Wigren (1999), but this mortality was not correlated with lameness, because 64 of the 65 piglets affected by lameness during this period survived for more than three days.

During all the other periods there was an increased mortality rate (day 3 to three weeks, $p < 0.01$; three weeks to five weeks, $p < 0.001$, five weeks to nine weeks, $p < 0.001$) among the gilts with arthritis. In contrast, there was an increased mortality rate ($p < 0.001$) only at the end of the suckling period among the barrows with arthritis, that is, when they were between three and five weeks of age. This difference between the sexes may be related to the fact that the affected gilts, but not the affected barrows, tended to be smaller than their penmates. Smaller piglets are generally restricted to poorer producing nipples (Simenson and Karlberg 1980; Vales et al., 1992; Lay et al., 2002), and obtain less milk and antibodies, and lame piglets that die are commonly undernourished (Svendsen et al., 1988).

Relationship with parity of sow

Lameness was diagnosed in about every second litter (papers **I**, **II**) and on average about two piglets were diagnosed in the affected litters. However, arthritis could be diagnosed in up to nine piglets within a litter. In the third study (paper **III**), lameness was also diagnosed in about every second litter in the systems with solid concrete floor, but only in about every fourth litter in the system with deep litter peat. The number of affected piglets in affected litters that system ranged from 1 to 3.

Despite the possibility that sows are more resistant to microorganisms than gilts (Goodwin 1965; Agarwal et al., 1969; Riising et al., 1976), the incidence of arthritis was slightly higher among the piglets born to sows of parity 3 than among the piglets born to gilts (11.4% versus 9.9%). This difference may be related to the larger litters and heavier piglets produced by sows of parities 2 and 3 compared with those produced by gilts (Baas et al., 1992), as was also observed in the first study (paper **I**). Heavier piglets are more likely to suffer from abrasion at feet and legs from wear against the floor, and any abrasion may provide a source of infection that might contribute to the development of arthritis (Nielsen et al., 1975a, b).

Mottotou and Green (1999) showed that the development of skin lesions was related to the time that the skin was in contact with the floor. An increased time spent in the heated creep area also increased the likelihood for skin damage. In this context, the incidence of treatments for arthritis from birth to 14 weeks was reduced by 90% in a Swedish herd of pigs following transfer to a deep-litter bedding with peat system introducing (J. Vallgårda, personal communication). In concordance with this observation the overall incidence of lameness was decreased, and lameness was only diagnosed in every fourth litter in the system with deep litter peat compared to in every second litter in the systems with solid concrete floor (paper **III**).

Relationship with litter size

The highest mortality rates (Tyler et al., 1990) and incidences of streptococcal infections (Riising et al., 1976) have been reported in litters with 12 piglets or more. In the first study (paper **I**) the incidence of lameness was 8.4% among the 4,546 piglets in litters with less than 12 piglets, and significantly higher, 11.1% ($p < 0.001$), among the 4,865 piglets in litters with 12 or more piglets. Although the total milk production of the sow tend to increase in large litters (Toner et al., 1996), the average amount of milk per piglet tends to be decreased, and it is likely that increased aggression between the piglets increases the risk for development of skin lesion, especially during the first few days of life (Bille et al., 1974; Mouttotou and Green 1999).

Health status of dam

No significant relationship between the health status of the dam and lameness in the offspring was observed (papers **I**, **III**). In the first study (paper **I**), the incidence of lameness was 10.3% among the 292 piglets delivered by a dam that had been treated medically during lactation, compared with 9.8% among the 9,119 piglets delivered by apparently healthy sows.

In the herd with three different farrowing systems (paper **III**) mastitis was observed in four sows (27%) in the deep litter system with peat, in two sows (18%) in the old solid concrete floor and one sow (9%) on new solid concrete floor between the first and the third day after farrowing. During the second week after farrowing, mastitis was observed in the new and old solid concrete floor in the farrowing pens (9% versus 18%), but not in the deep litter system. Constipation of sows due to peat consumption has frequently been recorded, but not feasible linked to the increased incidence of mastitis (Larsson et al., 2000). Still, the incidence of mastitis close to farrowing was highest in this system. However, no correlation between mastitis in the sow and lameness in the offspring was recorded in any of the systems.

Age when receiving iron dextran

Because piglets are born with a small reserve of iron and the milk of the sows contains low amounts of iron (Venn et al., 1947), piglets have to be supplemented with iron (Framstad and Sjaastad 1989). However, the iron supplied could potentially also be utilized by bacteria, and contribute to development of disease (Morris et al., 1995). As a result, the age when piglets receive intramuscular iron injections may influence the incidence of neonatal arthritis (Holmgren 1996). However, in the first study (paper **I**), there was no correlation between the day (living day 2, 3 or 4) on when the iron was administered and the subsequent incidence of arthritis.

Relationship with calendar month

The incidence of streptococcal infections has been reported to be highest during the winter (Riising et al., 1976), probably because, the indoor climate is influenced by the outdoor climate, even in units with heating facilities (Beskow et al., 1998). There were variations between the four years (paper **I**) in the prevalence observed in some months, particularly February, May, June, July and September. In each year the mean prevalence was highest in November 15.1 ± 2.2. This was the month when the mean outdoor temperature decreased to below 0°C in three of the four years, which in turn probably induced variation in the indoor climate over the day.

Influence of age on skin lesions

The skin normally forms a complete anatomic and physiologic barrier between the animal and its environment (Cameron 1999), but at birth the skin of the piglets is both soft and wet and could therefore be particularly sensitive to irritants or trauma. Small-abraded areas may in turn act as source for infections obtained from the environment.

In the field studies (papers **II**, **III**, **IV**), skin lesions in piglets were generally bilateral and most commonly observed as abrasions over the carpal joints.

In the herd with solid concrete floor embedded with straw and chip (paper **II**), totally 175 piglets were inspected at living day 3. Skin lesion were dominated by moderate to severe lesions and most commonly observed at carpus (88.6% day 3, 89.2% day 10). The incidence was similar on day 17, but at that time dominated by minor to moderate lesions.

On day 3, the skin lesions at carpus were dominated by mild to moderate lesions in all three farrowing pen systems (paper **III**, 63% in the new concrete floor with dunging area, n = 117; 58% in the old solid concrete floor, n = 120 and; 53% in the deep litter peat system, n = 153).

In the concrete floor systems (Figure 2), these lesions increased in prevalences and magnitudes until day 10, but decreased at day 17 (via 77% to 41% in the new concrete floor; via 73% to 27% in the old concrete floor). Interestingly, the preavalence of the carpal lesions was decreased already on day 10 in the deep litter peat system, and was from that day significantly lower than in the other systems; 37% at day 10 ($p < 0.001$) and 14% at day 17 ($p < 0.05$).

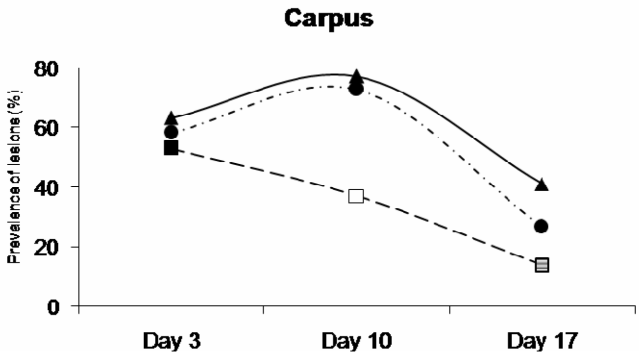

Figure 2. Prevalence of skin lesions scored as 1-3 at carpus in three different farrowing pen systems. Triangles represent a new solid concrete floor embedded with chopped straw, circles represent an old solid concrete floor embedded with chopped straw and squares represent a deep litters system with peat. Symbols other than black represent a statistic difference to black within examination day (shade = $p < 0.05$; grey = $p < 0.01$; white = $p < 0.001$).

At 3 days of age, the prevalence of skin lesions at carpus ranged from 34% to 61% in the four groups (paper **IV**, Figure 3). In comparison to the control group with abrasions in 61% of the piglets (n = 335), piglets born on the repaired floors had the lowest ($p < 0.001$) prevalences of abrasions at carpus (40% in Group III - Piglet Floor®, n = 243; 34% in Group IV - Thorocrete SL®, n = 285). Also the doubled straw ration decreased ($p < 0.01$) the abrasions (49% in group II, n = 210).

Skin lesions at carpus increased somewhat in magnitude until day 10 and thereafter declined in all four groups. On day 10 and day 17 of age, the prevalence of skin lesions at carpus in piglets born on the repaired floors (44% and 21% in Group III, 42% and 20% in Group IV) was significantly ($p < 0.01$ to 0.001) lower than in the control group (65% and 36%). At 10 days of age, also the group with the doubled straw ration (group II) had a lower ($p < 0.05$) incidence of skin lesions at carpus (53%) than the control group (Figure 3).

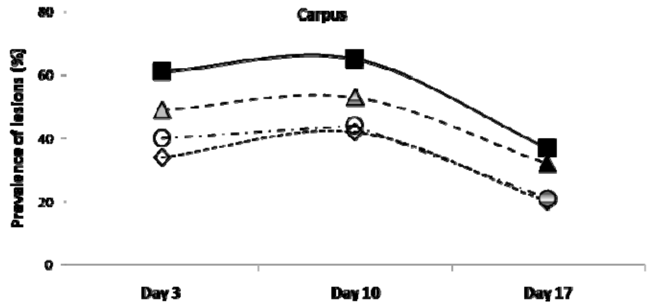

Figure 3. Prevalence of skin lesions scored as 1-3 at carpus in four experimental groups. Rectangles represent Group I – control, triangles represent Group II – with doubled chopped straw, circles represent Group III - Piglet Floor®, and rhombs represent Group IV - Thorocrete SL®. Symbols other than black represent a statistic difference to black within examination day (shade = $p < 0.05$; grey = $p < 0.01$; white = $p < 0.001$).

A similar pattern as for carpus, but at lower magnitudes, were observed with respect abrasions over the hocks and skin lesions at the face, at abdomen and teats or the tail (papers **II**, **III**, **IV**). These observations corresponded well to the distribution pattern of skin lesions previously reported by others (Penny et al., 1971; Gravås 1979; Svendsen et al., 1979; Furniss et al., 1986; Mouttotou et al., 1999a, b).

In the second study (paper **II**), lower magnitudes but still with decreasing prevalences with time, was observed with respect to lesions at hocks, faces and tails. The abdominal & teat abrasions increased from day 3 to day 10, but were practically disappeared on day 17. Omphalitis was not observed in any piglet.

At 3 days of age, piglets born on an old concrete floor expressed a lower ($p < 0.01$) incidence of lesions at the hocks compared to piglets born on a new concrete floor and the deep litter system (paper **III**). In contrast, a higher ($p < 0.01$) incidence of abrasion at abdomen and teats was seen in piglets born on the old floor. Abrasions at hocks and the abdomen decreased from day 3 to day 10, and had practically vanished on day 17 in all three farrowing pen systems. The incidences of skin lesions in the face ($p < 0.001$) and tail ($p < 0.05$) were significantly higher in the deep litter peat system than in the other systems when the piglets were aged 3 days, but not later.

At the third day of life, the lesions recorded at hocks, abdomen, face and tail were of lower magnitudes in comparison to those recorded at carpus in all four groups (paper **IV**). These lesions had practically vanished on day 10 and day 17. In contrast, the lesions in the face increased significantly at day 10 and day 17 in the control group in comparison to the groups with repaired floors ($p < 0.001$) and the group with doubled straw ration ($p < 0.01$).

Male piglets were castrated at the age of 3-5 days. Healing castrations wounds were examined at the 10th and 17th day of age. A low incidence of mild inflammations were recorded in all field studies (papers **II**, **III**, **IV**). However, mild inflammations were recorded in the meagre half (48%) of the piglets in the on the old solid concrete floor system (paper **III**), which differed from the new solid concrete floor system (18%) and the deep litter peat (15%). At day 17, healthy healing processes without inflammation, eczema or oedema were generally seen in all three farrowing pen systems, but inflamed castration wounds with purulence were observed in 3 piglets on the old solid concrete floor. Also the incidences of abrasions at abdomen and teats were highest in the system with an old concrete floor (paper **III**). This system had a solid concrete floor in the dunging area, possibly indicating a dirtier environment thus in the other systems. Draining floors facilitate removal of dung and thereby potentially decrease the pathogen load, and an increased proportion of the draining floor over the dunging area is generally considered to promote the box hygiene (Westin and Algers 2006).

Influence of age on foot lesions

The development of foot lesions is at any age dependent upon the characteristics of the floor and the resistance of the horn tissue to injury (Gardner et al., 1990; Walton 1995; Mouttotou and Green 1999). Foot lesions may easily develop very early in life since newborn piglets have extremely soft horn tissues on the soles, which becomes harder with age (Clark 1983). Almost all piglets are previously reported to develop sole bruising within the first four days of life and sole erosions increases between birth and 12 day of age, thereby also potentially decreasing the activity including suckling (Mouttotou and Green 1999).

In the second study (paper **II**), 87.4% of the piglets had developed sole bruisings and a similar figure was recorded on day 10. At day 17 the prevalence of sole bruising was decreased to 38.8%. During the entire period, moderate lesions dominated.

Sole bruising were more commonly observed in the systems with solid concrete floor and both these systems differed significantly from the deep litter peat system. The most severe abrasions at soles were seen in piglets kept on the new solid concrete floor (paper **III**; Figure 4).

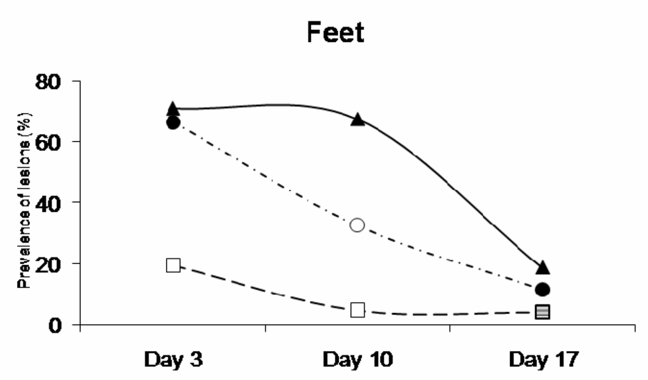

Figure 4. Prevalence of feet lesions scored as 1-3 in three different farrowing pen systems. Triangles represent a new solid concrete floor embedded with chopped straw, circles represent an old solid concrete floor embedded with chopped straw and squares represent a deep litters system with peat. Symbols other than black represent a statistic difference to black within examination day (shade = $p < 0.05$; grey = $p < 0.01$; white = $p < 0.001$).

In the fourth study (paper **IV**), the sole bruising scores of the control group were higher than the other three groups at three days of age ($p < 0.001$). At day 10, sole bruisings had decreased ($p <$ 0.01-0.001) within each group, but were more commonly observed in the control group and the group with doubled straw ration which both differed significantly ($p <$ 0.05-0.01) from the groups with the repaired floors (Figure 5).

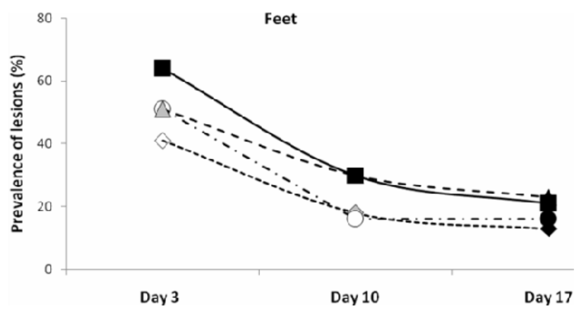

Figure 5. Prevalence of feet lesions scored as 1-3 in four experimental groups. Rectangles represent Group I – control, triangles represent Group II – with doubled chopped straw, circles represent Group III - Piglet Floor®, and rhombs represent Group IV - Thorocrete SL®. Symbols other than black represents a statistic difference to black within examination day (shade = $p < 0.05$; grey = $p < 0.01$; white = $p < 0.001$).

Influence of the environment on development of skin and foot lesions

Foot and skin lesions can cause lameness at piglets, either because of pain or due to an entrance for infections (Penny et al., 1971; Gardner et al., 1990; Zoric et al., 2004). If inducing bacteremia, arthritis, endocarditis, or meningitis may develop (Windsor 1978; Higgins and Gottshalk 2006). As all piglets were handled by the same staff (papers **III**, **IV**), the results of these studies obviously suggest that the immediate environment plays a primary etiological role in the appearance and development of abrasions and sole bruising, and consequently also to arthritis in suckling piglets. The explanation is to find in the damage potential of the floor, which depends of the contact surface and the resistance of the piglet. If the force in a strain exceeds the resistance of the skin or the sole a physical damage will arise (Newton et al., 1980; Christison et al., 1987; Dewey 2006; Holmgren et al., 2008).

Association between skin lesions scores at different sites within day

There was a significant positive correlation between skin lesions of carpus and hock within all examination days in the selected piglets with known identity (n = 48, six from each of 8 litters). A significant positive correlation was also noticed between skin lesions of hock and tail on day 3. During the tenth and seventeenth day of age a significant positive correlation between skin lesions of carpus and face and foot lesions were recorded, as well as between lesions at abdomen & teats and face (paper **II**).

The significant positive association between skin lesions of carpus and hock and between skin lesion of hock and tail on the third day of age presumably mirrored the contact with the surface of the floor during the intensive suckling carried out at that time. A significant positive correlation between the mean duration of each suckling episode and carpal skin abrasions in piglets aged three to six days as well as a positive relationship between the time spent lying in the creep area and the incidence of skin abrasion during the first three days of life have previously been reported (Gardner et al., 1994; Mouttotou and Green 1999). The suckling behaviour of the piglets (thrusting movements) is suggested to contribute to the distribution of the lesions (Smith 1979). So-called congenital splay-leg of piglets could play a part in the aetiology of the lesions on the hock and rump, and lesions on the chin and sternum seem to be precipitated by abrasion when suckling or when resting in the creep area with neck outstretched (Penny et al., 1971).

Association between skin lesions scores within sites between ages

A statistically significant positive correlation between lesion of the tail between day 3 and day 10 of age was recorded. Between day 10 and 17 significant positive correlations at all examination sites were found with exception of abdomen & teats (paper **II**).

There was a significant positive correlation between skin lesions of carpus and face and foot lesions during the tenth and seventeenth day of age as well as between these days. These associations presumably mirrored that skin lesions and sole bruisings develop progressively; at first the piglets had mild lesions in skin and soles, which developed into moderate lesions between three and ten days of age. From 10 to 17 days of age the sole bruisings healed somewhat. According to Mouttotou and Green (1999), piglets with sole erosions and sole bruising generally spent less time suckling, and more time lying at the side of the sow. Piglets with skin abrasions also spent significantly less time doing "other activities", possibly indicating that they were responding to pain with inactivity (Mouttotou et al., 1999a).

Bacteriological findings and antimicrobial susceptibility

Joint swelling and lameness are the most obvious and persistent clinical signs of infectious arthritis. Piglets can be infected with different pathogenic or facultative pathogenic microorganisms either directly from the sow and/or via the environment. Invading bacteria may enter the bloodstream via skin wounds, the navel or the tonsils (Windsor 1978). In lame piglets under 12 weeks of age the causative agents of arthritis have been reported to include *Streptococcus dysgalactiae* subsp. *equisimilis* (26.3%), *Staphylococcus hyicus* subsp. *hyicus* (24.6%), *Arcanobacterium pyogenes* (13.2%), *Staphylococcus aureus* (7.9%), and *Haemophilus parasuis* (7.9%), and most of the pigs culled for arthritis were under 6 weeks of age (Hill et al., 1996). The streptococci domination suggests the sow to be a significant source of infection to the piglets (Woods and Ross 1977; Hommez et al., 1991; Bara et al., 1993).

In the field studies (papers **II**, **III**, **IV**), occasional lame piglets were culled instead of medically treated. These piglets were subjected to necropsy including histopathological and microbiological examinations.

In the second study (paper **II**), necropsy of five piglets confirmed arthritis in at least one limb. Affected joints were variably swollen and lesions were most commonly seen in elbows and tarsal joints (4 of 5 piglets) and least commonly observed in the joints of the feet. Swelling caused by fluid accumulation was most readily detected in the elbow, stifle and carpal joints.

A bacterial aetiology was established by cultivation as *Streptococcus dysgalactiae* subsp. *equisimilis* (2 piglets) or *Staphylococcus hyicus* subsp. *hyicus* (2 piglets). No bacterial growth from affected joints was recorded in one piglet, but the macroscopic examination revealed swelling and accumulation of fluid in the joint space of that pig.

In paper **III**, eight lame piglets (3 from each of the solid floor systems and 2 from the peat system) were culled instead of medically treated. A fracture of the left humerus was the main diagnose in one pig, but a fluid accumulation was also seen in both elbows of that pig. The other seven pigs suffered from acute fibrin-purulent arthritis, and 5 of the piglets were affected in more than one joint. Bacterial cultivations of three joints per animal demonstrated microbial growth in all piglets. The findings were *Streptococcus dysgalactiae* subsp. *equisimilis* in 5 piglets (9/24 joints), *Staphylococcus hyicus* subsp. *hyicus* in 5 piglets (6/24 joints) and *Escherichia coli* in 2 piglets (2/24 joints). Different bacterial growths were recorded in four piglets, two piglets with *Streptococcus dysgalactiae* subsp. *equisimilis* and *Staphylococcus hyicus* subsp. *hyicus* and two piglets with *Staphylococcus hyicus* subsp. *hyicus* and *Escherichia coli*, respectively.

Twenty piglets were ensured a definitive diagnosis in paper **IV** - arthritis and isolated microorganisms (subacute arthritis - 3 piglets, acute fibrin-purulent arthritis - 2 piglets, acute purulent arthritis - 14 piglets, chronic arthritis - 1 piglet). Fifteen of these piglets (75%) were affected by polyarthritis or at least hit by infection in more than one joint. The microbiological cause was dominated by streptococci (60%), but also staphylococci (35%) and *E. coli* (5%) was demonstrated.

The microbial cause of lameness in piglets may vary and treatment of lame pigs leads to a permanent use of antibiotics, which in turn may lead to antimicrobial resistance. Therefore, a causative diagnose, including defining of minimum inhibitory concentration (MIC) values, ought to regularly be made from joints of lame piglets in pig herds. In these studies (papers **II**, **III**, **IV**), bacterial cultivations revealed *Streptococcus dysgalactiae* subsp. *equisimilis* as the dominating cause of infectious arthritis followed by *Staphylococcus hyicus* subsp. *hyicus* which concur with several other reports (Smith and Mitchell 1976; Nielsen et al., 1975b). These isolates were sensitive to all antibiotics included in the VetMIC™ Large Animal panel. However, *E. coli*, which generally has another antimicrobial sensitivity, was also demonstrated and this highlights the need of bacterial cultivations.

Antibodies to *Streptococcus dysgalactiae* subsp. *equisimilis*

In the second study (paper **II**; Figure 6), the level of serum antibodies to *Streptococcus dysgalactiae* subsp. *equisimilis* in 8 dams decreased during the last month of gestation and a maternal immunity to *Streptococcus dysgalactiae* subsp. *equisimilis* was demonstrated in all piglets (n = 47) which declined during the first five weeks of life. Somewhat lower median levels of serum antibodies were recorded among the piglets that were treated against arthritis during the first two weeks of life (n = 8).

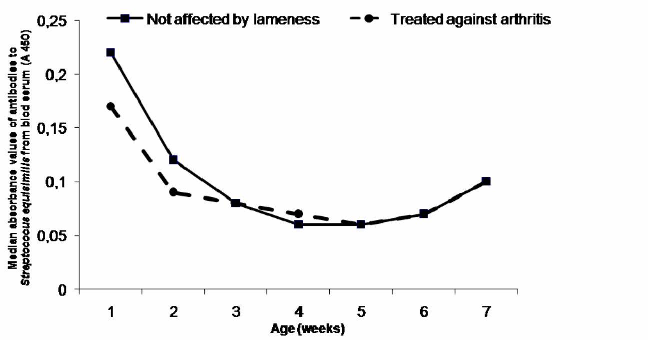

Figure 6. The median level of antibodies to *Streptococcus equisimilis* for 47 piglets (eight piglets treated against arthritis and 39 not affected by lameness) from the first week of life to the age of 7 weeks. The amount of antibodies are expressed as absorbance values (A_{450}) obtained by the ELISA described.

Streptococci specis may gain entry to the bloodstream after invasion via skin wounds, the navel or tonsils (Helms 1962; Sanford and Tilker 1982; Clifton-Hadley 1983). The source of infection is probably the sow (Riising et al., 1976). At this stage, maternal immunity, conferred by colostrum can play a protective role against bacteria (Butler 1973; Corbeil 1978; Klobasa et al., 1981; Saito et al., 1986; Roth 1999), and insufficient consumption of colostrums or inadequate levels of antibodies in colostrum may predispose for development of arthritis (Windsor 1978; Aumaitre and Seve 1978; Fu et al., 1990). However, these phenomenons requires further investigations to be fully validated.

Conclusions

Lameness in suckling piglets is an important problem in farrowing enterprises. Apart from animal suffering, lameness contributes to losses in form of dead piglets, decreased growth, and increased use of antibiotics and manual labour. The present study focused on pathogenic microorganisms and risks for lameness in different housing systems.

1. Lameness in suckling piglets was observed in about every second litter and around 75% of the treatments against lameness were effectuated in very young piglets, less than 3 weeks of age. Thereafter, the prevalence of treatments for arthritis and the incidence risk of developing lameness gradually decreased.
2. No difference in the incidence of arthritis between the sexes was seen. Nor was there any correlation between the day of parenteral iron administration (living day 2, 3 or 4) and lameness seen. These observations suggest that castration and iron injections by themselves not predispose to development of arthritis, provided that they are effectuated skillfully and under aseptic conditions.
3. The growth of piglets treated for lameness is retarded. At nine weeks of age barrows that had been treated for arthritis weighed 1.5 kg less than other barrows. The corresponding difference for gilts was 1.3 kg. Also the mortality was increased in piglets affected by lameness.
4. The litter size is of importance. The incidence of lameness was significantly higher among piglets in letters with 12 or more piglets.
5. The microbial cause of lameness in piglets varies, and laboratory diagnostic methods are therefore valuable.
6. Maternal immunity, achieved through colostrum may play a protective role against bacteria associated to development of arthritis.

7. Skin lesions were present already on day 3. They increased in magnitude until day 10 and thereafter declined. They were generally bilateral and most commonly observed as abrasions over the carpal joints. Hocks, face, abdomen and tails were affected in a similar way, but at lower magnitudes and these lesions had practically vanished on day 17 in all fields studies.
8. Sole bruisings were more commonly observed in systems with solid concrete floor than in a deep litter peat system and in farrowing pens with repaired concrete floors.
9. Floor maintenance decreased the significance of abrasions and sole bruisings, and also reduced the incidence of lameness. Also doubling the amount of chopped straw prevented lameness to some extent.
10. The overall incidence of lameness was decreased and lameness was only diagnosed in every fourth litter in the system with deep litter peat compared to in every second litter in the systems with solid concrete floor.

Aspects on future work

In order to prevent influence of pathogenic microorganisms and development of lameness in piglets, efforts are required to further improve the immediate environment of the newborn piglets. The work presented in this thesis indicates that the solution to a large extent is to find in the quality of the floor, and that the balance between potential damage of contact to the floor surface and the resistance of skin and soles in the piglets appears to be a key issue. Therefore, suckling behavior of the piglets is an area of particular interest since thrusting movements are suggested to contribute to the distribution of abrasions in nursing piglets.

The impact of the maternal immunity ought be further studied. Serum antibodies to *Streptococcus dysgalactiae* subsp. *equisimilis* detected by an indirect ELISA system revealed somewhat lower levels of serum antibodies during the first 2 weeks of life in the piglets that were treated against arthritis. Possibly, a vaccine can be prepared to increase of the transfer of the passive immunity from sows to piglets.

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