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Successful farrowing in sows

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Academic dissertation

To be presented, with the permission of
the Faculty of Veterinary Medicine, University of Helsinki,
for public criticism in Auditorium 5, Fabianinkatu 33, Helsinki,
on the 13th of August 2010, at 12 noon.

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ISBN 978-952-92-7636-3 (paperback)

ISBN 978-952-92-7637-0 (PDF)

Helsinki University Print

Helsinki 2010

To Cecilia, Filippo and Elena

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1. ABSTRACT

Years of genetic selection of breeding sows have considerably increased the number of piglets born in each litter of this multiparous species. This economically driven result has not always preceded the structural development of an environment that accommodates sows' physiological need for farrowing.

Farrowing is a complex event driven by several hormones that interact with each other to induce the onset of parturition. These hormones are responsible not only for the induction of parturition, but also for triggering visible behavioural changes. Activities such as rooting, pawing, turning and walking increase considerably 24h prior to farrowing and characterise what is known as nest-building behaviour. This behaviour very closely correlates with the environment of the sow before farrowing begins, and is stimulated by the presence of nest-building material such as roughage or straw. Modern housing systems have promoted the confinement of the farrowing sow to crates, which greatly limit the sow's movements and often preclude bedding or any other nest-building substrate. Perinatal mortality between countries and between herds varies considerably, but remains an important reason for the loss of piglets in their very first days of life. Excessively prolonged farrowing increases the number of stillborn or weak piglets.

The aim of this study was to determine which factors contribute to successful farrowing, thus reducing perinatal mortality and improving the welfare of sows and piglets at parturition. We aimed to test different movement sensors to measure changes in the farrowing-related activity of sows to facilitate the prediction of parturition in sows. We also sought to determine how the intensive housing of sows in crates affects the duration of farrowing, to identify some of the sow's hormonal parameters (cortisol, progesterone and oxytocin), to measure piglet mortality and growth, and identify which sow-related or environment-related factors affect the duration of farrowing. We also aimed to determine whether increasing the amount of crude fibre in the diet fed to sows in late pregnancy and early lactation would affect piglet growth and the body condition of the sow as well as reduce constipation.

The average general activity of the sows, monitored with movement sensors, was higher in the 24-h interval prior to farrowing than in all the other 24-h intervals monitored ($p < 0.05$). The duration of farrowing was on average 89 to 93 min longer in the sows housed in a farrowing crate than in the sows housed in a farrowing pen ($p < 0.05$). The average concentration of the post-expulsion oxytocin pulses (measured within 6 min after expulsion of the piglets) for the sows housed in farrowing crates tended to be lower (38.1 ± 24.6 pg/ml; $n = 9$) than for the sows housed in pens (77.6 ± 47.6 pg/ml; $n = 9$; $p = 0.08$). The duration of farrowing strongly associated with the oxytocin values ($p < 0.001$). Sows with a duration of farrowing longer than 300 min had 1.3 ± 1.3 (mean \pm SD) stillborn piglets in study I, and 1.5 ± 1.8 stillborn piglets in study IV, whereas sows with a duration of farrowing shorter than 300 min had 0.6 ± 1.0 stillborn piglets in study I, and 0.4 ± 0.8 stillborn piglets in study IV ($p < 0.001$). Higher back-fat values ($p < 0.001$) and lower constipation index scores ($p < 0.01$) indicative of constipation, negatively affected the duration of farrowing. The sows fed with a 7% crude fibre diet (FIBRE) had an average constipation score of 2.1 ± 1.3 (mean \pm SD), whereas the sows fed with a 3% crude fibre diet (LACT) had an average score of 1.2 ± 1.1 ($p < 0.001$). Moreover, 22% of the sows in the LACT group exhibited extremely severe constipation (more than five consecutive days without producing faeces), whereas only 5% of the sows in the FIBRE group showed this condition ($p < 0.05$).

In conclusion, sows housed in crates exhibited a longer duration of farrowing, a lower concentration of oxytocin during parturition and a higher number of stillborn than did sows housed in pens. Allowing the sow to move freely immediately before and during farrowing, thereby reducing constipation and avoiding excessive fattening of the sow during late gestation, all seemed to be key factors in shortening farrowing time, and thus reducing perinatal mortality. Photocells and force sensors reliably measured the activity of crated sows, thus enabling the development of an automated system for predicting the onset of parturition. Increasing the amount of crude fibre in the diet during late pregnancy and early lactation promoted intestinal function and water intake, thereby drastically reducing the risk for prolonged and severe constipation while having no substantial negative effect on the energy balance-related parameters of the sow.

2. LIST OF ORIGINAL ARTICLES

This thesis is based to four original articles (I-IV). These articles are referred in the text by their Roman numericals.

I

Oliviero C, Heinonen M, Valros A, Hälli O, Peltoniemi OAT
Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation
Animal Reproduction Science, 2008, 105: 365-377

II

Oliviero C, Pastell M, Heinonen M, Heikkonen J, Valros A, Ahokas J, Vainio O, Peltoniemi OAT
Using movement sensors to detect the onset of farrowing
Biosystems Engineering, 2008, 100: 281-285

III

Oliviero C, Kokkonen T, Heinonen M, Sankari S, Peltoniemi OAT
Feeding sows a high-fibre diet around farrowing and early lactation: Impact on intestinal activity, energy balance-related parameters and litter performance
Research in Veterinary Science, 2009, 86: 314-319

IV

Oliviero C, Heinonen M, Valros A, Peltoniemi OAT
Environmental and sow-related factors affecting the duration of farrowing
Animal Reproduction Science, 2010, 119, 85-91.

3. ABBREVIATIONS

EDTA	Ethylenediamine tetra-acetic acid
EIA	Enzyme immunoassay
ELISA	Enzyme-linked immunosorbent assay
¹²⁵ I	Iodine-125
KIU	Kallikrein inhibitor units
LH	Luteinizing hormone
NEFAs	Non-esterified fatty acids
PGF ₂ α	Prostaglandin F ₂ -alpha
RIA	Radioimmunoassay
rpm	Revolutions per minute
USB	Universal serial bus
UV	Ultraviolet

4. INTRODUCTION AND REVIEW OF LITERATURE

4.1 General Introduction

Farrowings are key events in the life of the sow that have a substantial economic impact on piglet production. Years of breeding selection in pig production have achieved excellent results, including increases in both the total number of piglets born in each litter as well as their average birth weight. Feeding strategies have also aimed to increase the milk yield of the sow in order to better support the growth of all the piglets during the weaning phase (Einarsson and Rojkittikhun, 1993). The productive cycle has also become faster, with a reduced lactation period and a shorter weaning-to-oestrus interval in order to maximise the number of piglets each sow delivers annually and to face productive competition and efficiency. Swine breeding farms have become larger with more sows than in the past, often with a functional distribution of the spaces that limit the room available for each sow. All these changes have contributed to increasing environmental pressure on the sow at farrowing. Prewaning mortality varies from country to country, from region to region, from farm to farm, but is on average quite high, ranging from 10% to 20% (Cutler et al., 2006). Of this high rate, more than half of the deaths occur in the first four days of life, and most of these in the first 36 hours of life (Svendson, 1992; Tuchscherer et al., 2000). Perinatal mortality is not only one of the major causes of economic loss in piglet production, but also poses a significant health and welfare problem. These farrowing-related problems clearly demonstrate just how crucial farrowing is and how much more attention should focus on this phase in the life of the sow in order to minimise the negative consequences.

4.2 Physiology of farrowing

Physiology of farrowing is very complex, and several hormones act and interact to regulate the farrowing process. In the latest stages of pregnancy, progesterone, LH, estrogens, cortisol, prolactin, relaxin, and prostaglandins become the main actors that regulate all the physical events leading to

parturition. All these hormones, regulated by various internal clocks, interact and influence each other in a very refined manner (Anderson, 2000). Behavioural expression is also very important for the farrowing process. Sows express an innate hormone-driven nest-building behaviour which signals the beginning of parturition (Algers and Uvnäs-Moberg, 2007). However, the environment can also have an important, though indirect, influence on the pattern of these hormones. A restricted environment can also influence this nest-building behaviour, especially in the modern swine production system, where the sow is pressured by several external factors (Damm et al., 2003). This refined, delicate hormonal process clearly requires very well-defined premises in order to develop properly. In addition to housing, nutrition and disease may also affect, either directly or indirectly, the release or activity of farrowing hormones that interfere with the physiological process.

4.2.1 Hormones

During early pregnancy, after implantation of the embryos and the development activity of the *corpora lutea*, a higher and constant level of progesterone dominates the hormonal pattern (Meulen et al., 1988). This preserves the progress of pregnancy, and for almost two thirds of its length, the level of progesterone circulating in the blood will remain high. After the first trimester of pregnancy, most of the other reproductive hormones (oxytocin, prostaglandins, relaxin, prolactin) show very basal levels or very little pulsating activity (Fig. 1a) for the remainder of the pregnancy. This very stable hormonal activity changes completely 48-24 hours before the beginning of parturition. The quick drop in progesterone concentration produces a cascade effect on almost all the other hormones, which throughout the pregnancy remained quite stable. The level of prostaglandin peaks, the oxytocin concentration increases and begins to exhibit high pulsating activity (Gilbert et al., 1994), the prolactin concentration gradually increases, and estrogens, after peaking quickly, gradually drop to basal levels (Ellendorff et al., 1979; Kindahl et al., 1982; Anderson, 2000) (Fig. 1b). It is remarkable how such large hormonal changes occur in such a very limited amount of time.

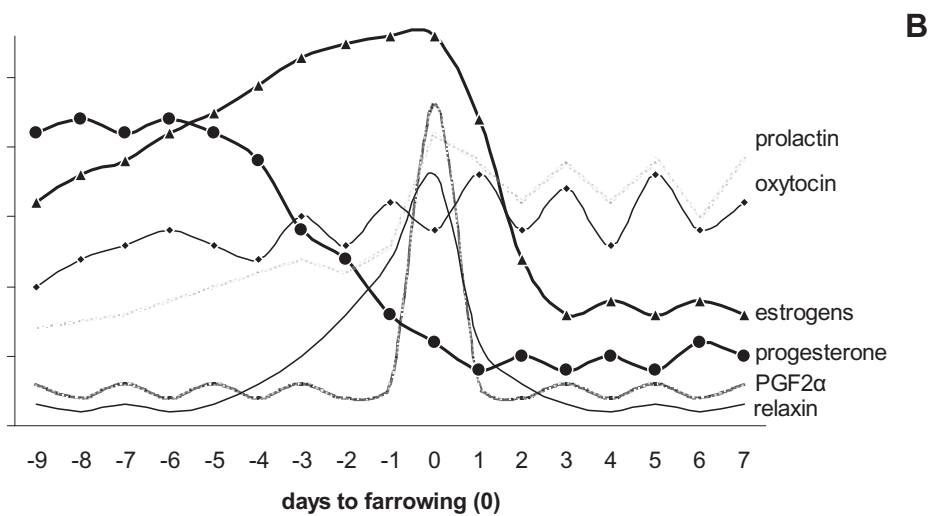
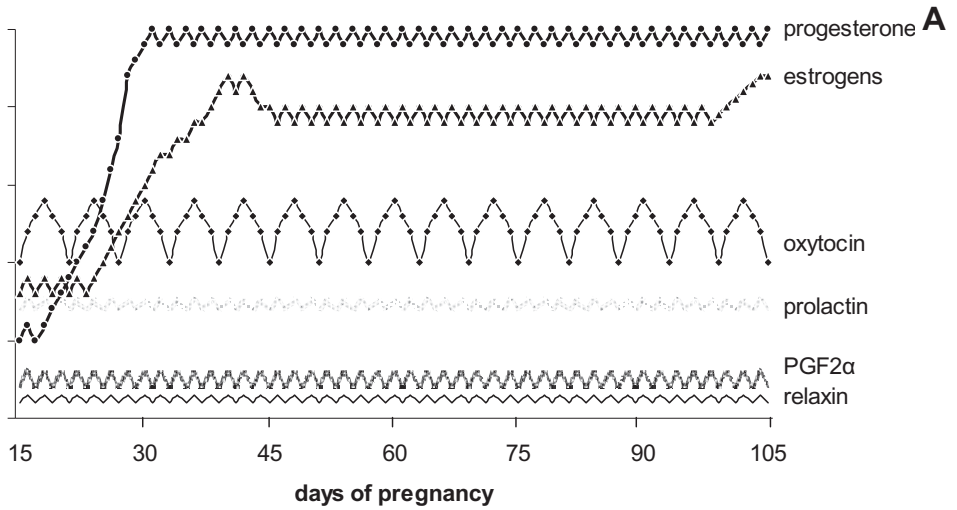


Figure 1. A schematic description of the level of reproductive hormones during pregnancy in the sow (modified from Anderson, 2000). Soon after early pregnancy, reproductive hormones show very stable levels for almost the entire pregnancy (A). Hormones levels undergo major changes only a few days before farrowing (B).

4.2.2 Behaviour and activity

Before and during farrowing, the intense hormonal activity described above is responsible not only for inducing the parturition event, but also for triggering visible behavioural changes. Activities such as rooting, pawing, turning and walking increase considerably 24 h prior to farrowing (Hartsock and Barczewski, 1997) and characterise the nest-building behaviour. One of the triggering factors of nest-building behaviour has been found to be a rise in prolactin (Castren et al., 1994), induced by a decrease in progesterone and an increase in prostaglandin (Algers and Uvnäs-Moberg, 2007). The external influence of the environment is also important for the expression of nest-building behaviour. The availability of proper nest-building material seems to speed up this process (Damn et al., 2000). Modern housing systems have promoted the confinement of the farrowing sow in crates, where the sow has very limited movement and where bedding or any other nest-building substrate is often absent. In these particular conditions, the nest-building behaviour triggered by endogenous hormonal activity cannot find proper expression. In the absence of a nest-building substrate, confined sows express prolonged and unsuccessful nest-building behaviour (Damn et al., 2003). The lack of opportunity to express appropriate nest-building behaviour can lead to an increase in cortisol and ACTH (Jarvis et al., 1997), which indicates a stressful condition. Gustafsson et al. (1999) found that domestic sows were able to build nests identical to those of wild boars, even after several previous farrowing experiences in confined crates without bedding. This innate behaviour is therefore a clear indicator of impending farrowing and occurs independently of the housing or the bedding material available.

4.2.3 Physiological signs of approaching farrowing

Other than behavioural signs, many clinical signs also give clear indications of impending farrowing. Several studies have demonstrated that a sow's body temperature, beginning 48-24 h before the onset of farrowing and ending 12 h before farrowing, gradually rises to 1°C-1.5°C higher than its normal body temperature and lasts until weaning (Elmore et al. 1979; King et al., 1972), (Fig. 2).

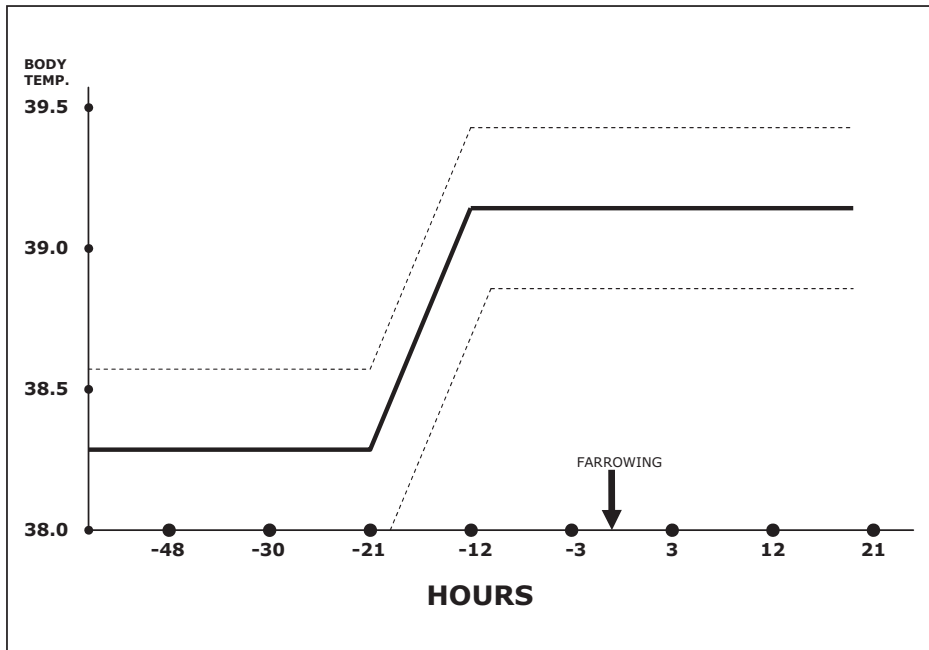


Figure 2. Body temperature of preparturient sows detected by radio telemetry. The area between the dotted lines shows the range of preparturient body temperatures (modified from Elmore, 1979).

The respiratory and heart rates also rise a few hours before farrowing, returning to normal after parturition (Kelley and Curtis, 1978) (Fig. 3). Other well-known signs of impending farrowing are the presence of milk in the udder and swollen vulva. As described previously, nest-building behaviour is also a very good predictor of upcoming parturition. A few hours before farrowing, the sow's normal activity level can increase three-fold (Fig. 4)

Observing changes in these signs already helps to predict the onset of farrowing in sows, but a more precise collection of data, with the help of technological devices, for example, could provide more accurate predictions.

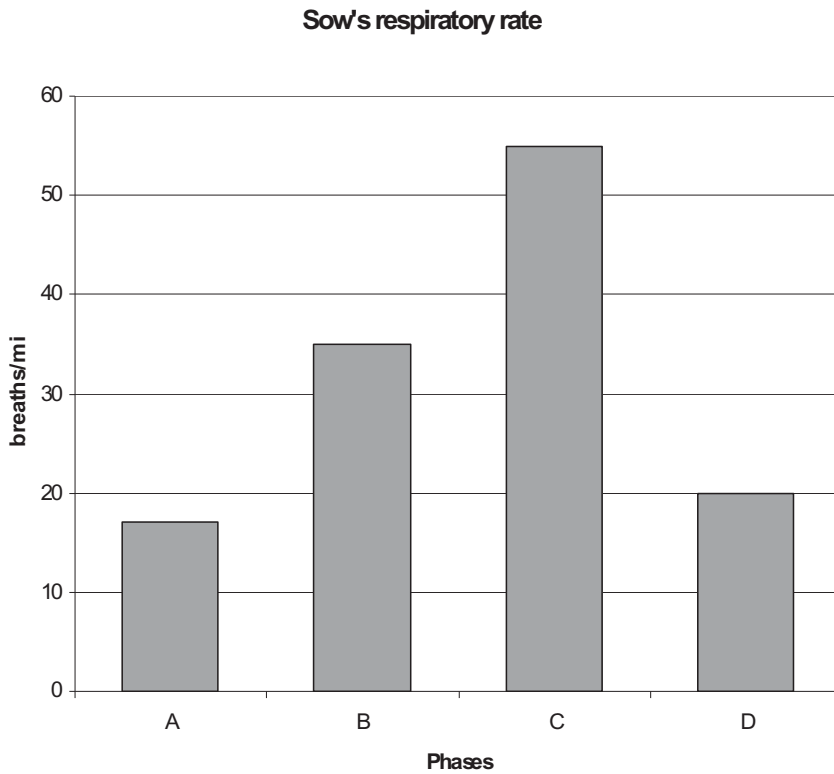


Figure 3. Respiratory rate (RR) in periparturient sows. Phases: A = normal RR; B = from 12 to 4 h before the first piglet is born; C = from the end of B until the last piglet is born; D = from the end of C to 4 d postpartum; arrow = onset of farrowing (data from Kelley and Curtis, 1978).

Sow's activity before farrowing

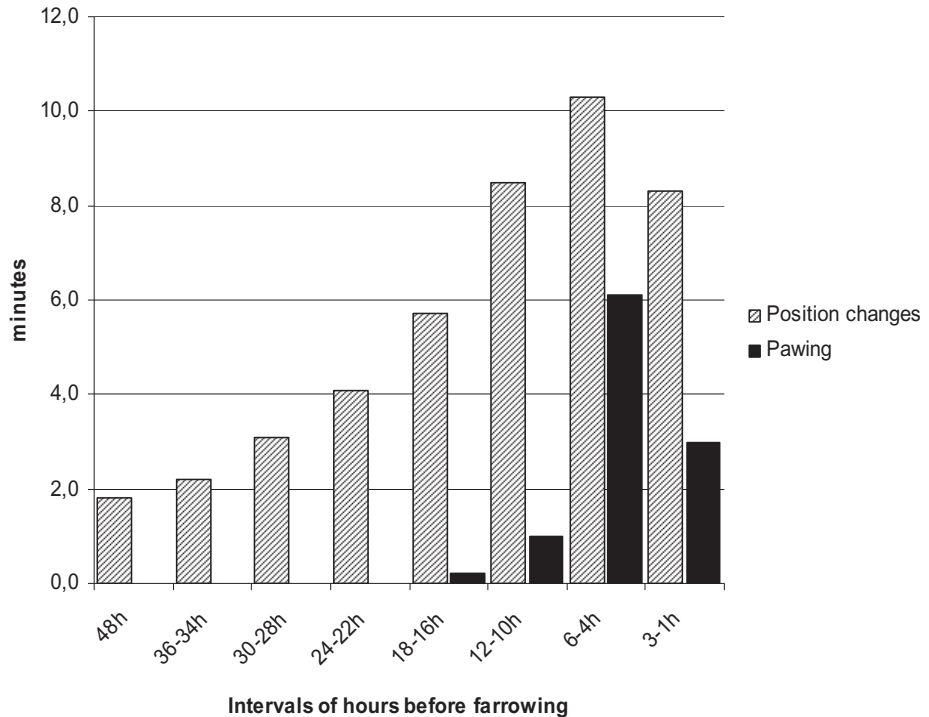


Figure 4. Preparturition activity in the sow (Hartsock et al. 1997). Average number of minutes sows spent changing position (e.g. standing to sitting and rolling) or pawing the floor in each interval of preparturition hours.

4.2.4 Duration of farrowing

The duration of farrowing can vary considerably and depends on several factors such as breed, age of the sow, length of gestation, number of piglets born, environment and body condition. Previous studies have calculated the duration of farrowing in sows and found that the average farrowing period ranges from 156 to 262 min (Randall, 1972; Madec and Leon, 1992; Von Klocek et al., 1992; Van Dijk et al., 2005). The duration of farrowing can play a key role in the survival of piglets and sow health. Being a multiparous species with a long duration of parturition, sows have variable number of stillborn piglets. Previous studies have demonstrated a direct connection between the

duration of farrowing and the number of stillborn; the longer the duration of farrowing, the higher the piglet mortality (Zaleski and Hacker, 1993; van Dijk et al., 2005). Additionally, evidence also suggests that a longer farrowing period can affect the health of the sow until early lactation (Martineau et al., 1992; Herpin et al., 1996; van Dijk et al., 2005). Longer birth intervals between piglets significantly correlate with a higher stillborn rate (van Dijk et al., 2005). Genetic selection, which remarkably increases the prolificacy of sows, consequently prolongs the duration of farrowing (Eissen et al., 2003). Giving birth to larger litters may not only extend the duration of farrowing, but may also increase the probability of dystocia or *inertia uteri* (Smith, 1997). When these problems occur, human intervention is essential in reducing the risk for serious complications in the litter and the sow itself.

4.3 Farrowing and the perinatal mortality of piglets

Perinatal mortality in the pig remains an unsolved problem. The exact causes of mortality in this phase are seldom well known due to the unreliability of diagnoses. However, previous research has provided valuable scientific data. Crushing has proved to be an important cause of perinatal death, but, as some studies have demonstrated, is often only the last event in a series of previous causal effects (Edwards, 2002). Hypothermia and starvation are usually underestimated, but are frequently the direct or the main predisposing cause of perinatal mortality. A higher number of stillborn or weak piglets may occur due either to dystocia during farrowing (Smith, 1997) or to excessively prolonged farrowing (Zaleski and Hacker, 1993; van Dijk et al., 2005). In the past two decades, breeding selection has steadily increased the number of piglets born; these piglets have been associated with a considerable rise in perinatal mortality (Boulet et al., 2008). The risk for perinatal mortality is higher in the first three days after farrowing, but can be reduced through human intervention (Holyoake et al., 1995), thus demonstrating that the hours immediately after farrowing are crucial for the survival of weak-born piglets.

4.4 Farrowing environment

The modern swine industry uses four basic types of farrowing accommodation: the farrowing crate, the sow pen, indoor group housing and outdoor extensive housing. In Europe, the most widely used are the sow pen and the farrowing crate, which is largely predominant (Jensen et al., 1997). The farrowing crate was designed to minimise piglet losses due to crushing and to improve management (Edwards and Fraser, 1997).

4.4.1 Housing: the crate and the pen

Farrowing crates usually consist of a system of bars which confine the sow to a limited space where she can lie down or stand, but cannot turn or move around. Farrowing crates are often placed on concrete, slatted floors or a combination of the two. The use of roughage or bedding for farrowing sows is regulated by European legislation describing only the minimum standards required (91/630/EEC). The situation can therefore vary considerably between countries, but roughage is usually very limited or completely absent. In this particular environment, the sow has fewer opportunities to express proper nest-building behaviour. In the absence of a suitable substrate, the sow directs its activities towards the floor and the bars of the crate (Lawrence et al., 1994). Crated sows stand up more often before the onset of parturition than do sows in pens (Hansen and Curtis, 1980). Some studies have found that keeping sows in crates reduces crushing more than does keeping them in pens (Olsson and Svendsen, 1989; Cronin et al., 1996), but several other studies have found no differences (Gustafsson, 1982; Aumaitre and Le Dividich, 1984; Fraser, 1990; Phillips and Fraser, 1993). Farrowing pens can vary in size and structure, however, with the larger ones permitting the sow to move freely and to turn around. During the 24 h before parturition, sows in pens turn and walk more frequently than do crated sows, whose activities are limited (Hartsock and Barczewski, 1997). Providing more space, even without straw, promotes the expression of maternal behaviour during farrowing (Jarvis et al., 2004). Vestergaard and Hansen (1984) found that sows under confinement before or during farrowing showed prolonged duration of farrowing. This increased farrowing time is either the direct result of less optimal conditions for nest-building or the indirect result of

subsequent stress. Because pens allow the sow to better express its nest-building behaviour, at least partially, they benefit the health and welfare of both the sow and the piglets (Algers, 1994).

4.5 Body condition, fat metabolism and gut function at farrowing

4.5.1 Body condition and fat metabolism

At the moment of farrowing, the sow's metabolism has already switched to a catabolic state, at which point it uses most of its body reserves to produce large quantities of milk (van den Brand and Kemp, 2005). Rising levels of blood NEFAs are clear indicators of a catabolic state associated with severe loss of body weight and low feed intake (Messias de Branganca and Prunier, 1999). Le Cozler et al. (1999) found that the circulation of NEFAs increases faster a few days before farrowing, reaching a peak on the day of parturition. As the sow approaches farrowing, its body prioritises the impending parturition and begins producing milk. On the other hand, feed intake and intestinal function decrease such that external sources of energy are replaced by a catabolic state that mobilises internal reserves of energy. As sows approach farrowing, a mild state of constipation is common because the intestine is less active due to upcoming parturition (Kamphues et al., 2000). This inner ability of the sow's body to reduce its intestinal activity in favour of other physiological needs, such as parturition, is also supported by other findings. Studies have found that increasing the energy of feeding in late pregnancy can negatively affect the sow's feed intake during early lactation. This reduction in feed intake is thought to be due to reduced glucose tolerance and insulin resistance caused by excess energy intake during late pregnancy (Fangman and Carlson, 2007).

4.5.2 Intestinal activity and constipation

Sows may often experience a state of constipation just prior to farrowing (Kamphues et al., 2000). In addition, water absorption in the intestine increases during this phase due to the fluid request resulting from the beginning of milk production (Mroz et al., 1995). Offering feed low in volume and fibre can worsen constipation, thus increasing the risk for absorbing bacterial toxins and targeting the udder (Smith, 1985). Other studies in which

constipated sows showed higher rates of mastitis (PDS, postpartum dysgalactia syndrome) than did unconstipated ones found evidence of a direct effect of constipation on udder health (Hermansson et al., 1978; Persson, 1996). During late pregnancy, one common practice of feeding sows aims to reduce the amount of feed offered and to increase the energy of the ration. Such concentrated diets usually contain more limited amounts of fibre than do standard pregnancy diets. This practice aims mainly to ensure that sows receive enough energy during late pregnancy to satisfy upcoming milk production (Einarsson and Rojkittikhun, 1993). This combination of a concentrated and low-fibre diet during a period of physiologically low intestinal activity can lead to severe constipation. Such a mass of solid faeces may create a physical obstacle during birth by pressing on the birth canal, thus resulting in greater difficulty during the expulsive stage (Cowart, 2007). The current lack of knowledge of how much such a state of severe constipation may also be a source of intestinal pain for the sows contributes to their declining welfare.

5. AIMS OF THE STUDY

This thesis includes research on factors affecting parturition in sows. We investigated which factors may contribute to successful farrowing, thereby reducing perinatal mortality and improving the welfare of sows and piglets at parturition. The specific aims of the work are listed below.

1. We wanted to determine how intensive housing of sows in crates affects the duration of farrowing, some of the sow's hormonal parameters (cortisol, progesterone and oxytocin), piglet mortality and growth.
2. We aimed to investigate the main factors believed to affect the duration of farrowing, including both sow-related factors and factors related to the management of the sow, such as housing, sow body condition and constipation.
3. We wanted to test different movement sensors to measure changes in the farrowing-related activity of sows in order to facilitate the prediction of parturition in sows.
4. We aimed to determine whether increasing the amount of crude fibre in the diet fed to sows in late pregnancy and during early lactation would improve intestinal activity (as an indication of motility of the gut) and thereby reduce the risk for developing severe constipation.
5. We wanted to determine whether increasing crude fibre in the diet fed to sows in late pregnancy and during early lactation would negatively affect the energy balance-related parameters of the sow and impact early piglet growth.

6. MATERIAL AND METHODS

This section presented an overview of the materials and methods for all the studies carried out (I-IV). A detailed description can also be found in the original publications reproduced in the last section of this thesis.

6.1 Experimental design

All the trials were carried out in a commercial piggery with standardised management practices: the first trial (I) took place in a fully integrated farm, whereas trials II, III and IV were carried out in sow-poll system farms. All the experimental protocols were approved by the Ethical Committee for Institutional Animal Use and Care of the Helsinki University.

In the first trial (I), we investigated the effect of housing on the physiology of the sow, including salivary cortisol, blood progesterone and oxytocin. In this study, our main focus was on the possible effect of intensive housing of sows in crates on the duration of farrowing and, by extension, on the associated hormonal parameters, piglet mortality and growth.

We also investigated the effect of housing on the duration of farrowing in the fourth trial (IV): a group of sows was permitted to farrow in a pen where the bars of the crate were kept open, thus enabling them to move around (Fig. 5).

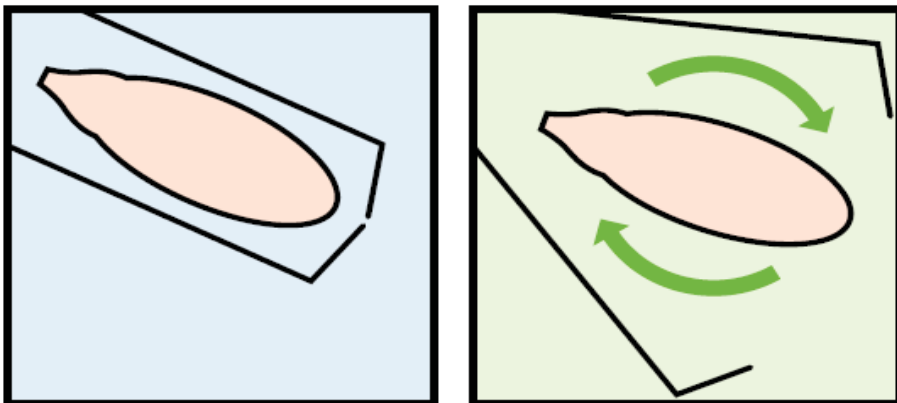


Figure 5. A schematic representation of how the farrowing crate was kept open, thus allowing the sow to move and turn around.

In addition, we explored the effect of several other factors, such as variables affecting the sow (body condition, intestinal activity, parity, length of gestation) and those affecting the piglets (total number born and stillborn), on the duration of farrowing.

In the second trial (II), we investigated changes in the sow's behaviour during the approach of farrowing in relation to its nest-building behaviour. We measured the crated sow's activity before farrowing by using different movement sensors that measure changes in its farrowing-related activity.

In the third trial (III), we studied the impact of dietary fibre on the sow's intestinal activity, energy balance-related parameters and litter performance during late pregnancy and early lactation. We doubled the amount of fibre in a standard commercial lactating diet fed to sows in late pregnancy and during early lactation and explored intestinal activity (as an indication of motility of the gut) and its effect on the energy balance-related parameters of the sow.

6.2 Animals, treatments and management

A summarised description of the animals, their treatment and management appears in Table 1.

Table 1. Data on the four studies

Study	No of animals	Housing	Nesting material	Parity	Fibre in feed (%)
I	18	Crate	none	1-7	3.8
	20	Pen	straw	1-7	3.8
II	18	Crate	none	1-6	3.8
III	40	Crate	none	2-8	7
	41	Crate	none	2-8	3.8
IV	115	Crate	none	1-8	3.8
	57	Pen	sawdust	1-8	3.8

Cross-breed sows (Finnish Yorkshire × Finnish Landrace) from Finnish commercial farms were used in all four studies. Parity of the sows ranged from one to eight. The sows were health classified according to the Finnish Health Scheme, indicating freedom from enzootic pneumonia, salmonellosis, sarcoptic mange, dysentery and atrophic rhinitis. The health of the animals was monitored before and during all the studies. The sows were fed commercial diets twice daily.

The sows housed in pens had a space allowance ranging from 210 to 220 cm in width and from 220 to 335 cm in length; the sows housed in crates had a space allowance of 80 x 210 cm.

6.3 Blood and saliva samples (I and III)

In study I, blood samples for the analysis of progesterone were collected from the vena saphena medialis. The blood samples were taken between 08:00 and 09:00 with ice-chilled EDTA tubes and centrifuged at 3000 rpm for 15 min; the plasma was then frozen at -20°C until analysis.

Additionally, we inserted an indwelling jugular catheter into 18 sows, approximately one week before the expected farrowing. This catheter allowed us to draw three blood samples (one every 2 min) immediately after the birth of the first ten piglets to determine the post-expulsion oxytocin pulse. Samples were drawn with ice-chilled EDTA tubes containing 500 KIU/ml of aprotonin (Trasylo[®], Bayer, Germany) to prevent early proteolysis of the oxytocin. The tubes were immediately centrifuged at +4°C at 3500 rpm for 10 min, and the plasma was stored at -70°C until analysis. The indwelling jugular catheter was fitted non-surgically to the sows via an ear vein. Sows were fastened around the upper jaw with a rope snare and tied to a fence while an intravenous catheter placement unit (14 G, 57 mm) was inserted into an ear vein, and a vinyl tube (o.d. 1.5mm × i.d. 1.0 mm) was passed through the catheter. The free tube was secured to the ear with adhesive tape wrapped around the ear, and the ear was fixed to the neck with a collar of adhesive tape. The free end of tube was stored in a Velcro pouch attached to the neck for easy sampling. The time taken for catheterisation was approximately 5–10 min.

To assess salivary cortisol, saliva samples were drawn with Salivette® tubes (Sarstedt AG & Co., Germany) containing a cotton swab, which was kept in the sow's mouth with metal forceps until the cotton became wet; this took 1 or 2 min. The swab was then placed back in the Salivette® tube and centrifuged at 3500 rpm for 10 min. This procedure allowed us to collect approximately 1.5 ml of saliva. The saliva obtained was then frozen at -20°C until analysis.

In study III, blood samples were collected from the *vena saphena medialis* twice daily: the first at around 08:00 (one hour before feeding) and the second at around 10:00 (one hour after feeding). The blood obtained was centrifuged at 3500 rpm for 10 min. The serum obtained was immediately frozen at -20°C until analysis of pre- and post-feeding values of non-esterified fatty acids (NEFAs), urea, creatinine, glucose and insulin.

6.4 Back-fat measurement (III and IV)

We measured the back-fat layer of the sows using a digital back-fat indicator (Renco lean-meater, Renco Corporation, Minneapolis, MN, USA). The back-fat digital indicator probe was placed on the back of the sow at the level of the last rib, 6 to 7 cm from one side of the backbone. Two consecutive measurements in the same spot were taken and averaged to obtain a more accurate final value. In study III, we took a total of five measurements for each sow: one on days 85 and 107 of gestation, at farrowing, during early lactation and at weaning. In study IV, the first measurement was taken between days 85 and 95 of gestation in the nucleus herd, and the second measurement at farrowing in the satellite herd (within two days before or after farrowing).

6.5 Hormone assays

6.5.1 Progesterone (I)

Plasma samples for progesterone were analysed using a commercial radioimmunoassay kit (Spectria® Progesterone RIA, Orion Diagnostica, Finland) validated to measure progesterone in pig plasma (Peltoniemi et al., 1995). A 50-ml plasma sample and 500 µl of buffered I¹²⁵ label were added to the antibody-coated tubes. After vortex mixing, the tubes were incubated at room temperature for two hours. The supernatant was decanted, and the

tubes were left standing upside down for five minutes. Each tube was counted for one minute in a γ -counter (Wallac[®], LKB-Wallac, Turku, Finland). The detection limit of the assay was 0.3 ng/ml, and the intra- and inter-assay coefficients of variation (CV) for three quality control concentrations were < 10%.

6.5.2 Cortisol (I)

Salivary cortisol was determined with a commercial radioimmunoassay (Spectria[®] Cortisol RIA, Orion Diagnostica, Finland), which we validated to measure cortisol in pig saliva. In the assay, 150 μ l of pig saliva and 500 μ l of buffered ¹²⁵I label were added to the antibody-coated tubes.

After 30 min of incubation in a 37°C water bath, the supernatant was decanted, and the tubes were washed with 1 ml of distilled water. The radioactivity in the tubes was measured with a gamma counter for 1 min. The human plasma standard curve provided by the commercial assay and the serial dilutions of pig saliva (1:1 to 1:10) showed parallelism, which indicated that the endogenous ligand and cortisol standard displaced the radioligand from the antibody in a similar manner.

The linearity of dilution had a recovery rate between 95% and 101% (n = 6). Some aliquots of pig saliva were inactivated with charcoal stripping to remove hydrophobic structures, including steroids such as cortisol. A 100-mg aliquot of activated charcoal was added to 2 ml of pig saliva and mixed at room temperature for 30 min. The saliva was recovered by centrifuging at 17 000 \times g at 10°C for 1 h. The supernatant was later filtered through 0.45- μ m and then 0.2- μ m filters (Minisart[®], Sartorius, Germany). The recovery rate of known quantities of human cortisol, added to stripped pig saliva and to pig saliva samples with a known level of endogenous cortisol, ranged from 99% to 107% (n = 6). The intra- and inter-assay precision for three salivary samples (high = 66 ng/ml, medium = 29 ng/ml, low = 3 ng/ml) in ten replicates yielded a coefficient of variation between 2% and 9%. The detection limit of the assay was 0.8 ng/ml. The cortisol antiserum cross-reacted with the following steroids: cortisol 100%, prednisolone 4.2%, fludocortisone 12.1%, 5 α -dihydrocortisol 8.8%, 21-deoxycortisol 8.6%, corticosterone 2.8%, 6 α -methylprednisolone, and prednisone 1.2%.

6.5.3 Oxytocin (I)

Plasma oxytocin was determined with a commercial enzyme immunoassay (Oxytocin EIA[®],

Assay Designs, USA) according to the manufacturer's instructions. The recovery rate of a known quantity of human oxytocin added to the porcine plasma was 104%. A sample containing 200 pg/ml of oxytocin was diluted five times at a ratio of 1:2 into assay buffer and then measured. The data were plotted graphically as the actual oxytocin concentration versus the measured oxytocin concentration. The line obtained had a slope of 0.995 and a correlation coefficient of 0.998.

The human plasma standard curve, provided by the commercial assay, and serial dilutions of the porcine plasma (1:2–1:10) showed parallelism. The detection limit of the assay for porcine plasma was 3.9 pg/ml, and the intra- and inter-assay CVs were, respectively, 12% and 20% for low values, 10% and 11% for medium values, and 10% and 5% for high values.

6.5.4 Insulin (III)

The insulin concentration was assessed using an ELISA assay (Porcine Insulin[®], Merckodia, Uppsala, Sweden) according to the manufacturer's instructions. The minimum detectable amount of standard in the assay was 0.05 µg/l. The concentration of insulin was obtained using computerised data reduction of the absorbance for the calibrators (except for calibrator 0) vs. the concentration using cubic spline regression. The intra-assay coefficient of variation (CV) for Porcine Insulin ELISA was 6.2% for low values (0.1 µg/l) and 3.6% for high values (0.9 µg/l; n = 10); the inter-assay CV was 12.6% for low values and 9.5% for high values (n = 20).

6.5.5 NEFA, Urea, Creatinine and Glucose (III)

Concentrations of NEFA were measured using an enzymatic, colorimetric method with a NEFA-C kit[®] (Waco Chemicals GmbH, Neuss, Germany) as described by Campbell et al. (1990). We determined the urea concentration with an enzymatic, kinetic UV method (Urea UV 250[®], BioMerieux, Marcy-l'Étoile, France) as described by Gutmann and Bergmeyer (1974).

A kinetic, colorimetric method (Creatinine-Jaffe[®], Thermo Fisher Scientific Oy, Vantaa, Finland) was used to measure creatinine as described by Fabiny and Ertigshausen (1971).

We measured the concentration of glucose with an enzymatic, colorimetric method (Glucose GOD-POD[®], Thermo Fisher Scientific Oy, Vantaa, Finland) as described by Trinder (1969).

6.6 Faeces evaluation (III and IV)

In these two studies, we monitored the intestinal activity of all of the sows, from five days before to five days after farrowing, thus making a daily qualitative evaluation of the faeces. The faeces were ranked every morning before the daily cleaning based on a visual qualitative evaluation. As described in Figure 6, we assigned a score of 0 to 5 as follows: 0 (absence of faeces), 1 (dry and pellet shaped), 2 (between dry and normal), 3 (normal and soft, but firm and well formed), 4 (between normal and wet; still formed, but not firm) and 5 (very wet faeces, unformed and liquid). In study III, we also classified the grade of constipation.


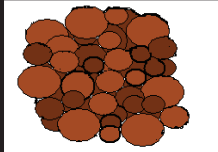
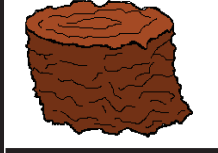

	0	Absence of faeces
	1	Dry and pellet-shaped (unformed)
	2	Between dry and normal (pellet-shaped and formed)
	3	Normal and soft, but firm and well formed
	4	Between normal and wet; still formed, but not firm
	5	Very wet faeces, unformed and liquid

Figure 6. The faecal score used to classify sow faeces in studies III and IV.

Depending on the number of consecutive days with no faecal production, we classified the grade of constipation as mild (no faeces for two consecutive days), severe (no faeces for three or four consecutive days) and extremely severe (no faeces for more than five consecutive days).

6.7 The movement sensors

Three farrowing crates were equipped with a thin-film ferro-electric force sensor (L-series, Emfit Ltd., Finland) sealed between two rubber carpets placed on the floor under the sows. The Emfit L-series force sensor is a cellular, biaxially oriented polypropylene film coated with metal electrodes. A photocell (E3F2, Omron Europe, the Netherlands) and a reflector, both placed at a height of 0.6 m, were also installed in each of the farrowing crates. The force sensor measured the overall movements of the sows, whereas the photocells were used to detect whether the sow was lying down or standing up. All sensors were connected to two USB data acquisition units (NI USB-6008, National Instruments, USA) using a single-ended connection for the photocells and a differential connection for the force sensors. The data were logged continuously with the dedicated computer programme LabViews v7.1 (National Instruments, USA). A video recording system was installed to assess the exact beginning of each parturition. We placed three video cameras on the wall 3 m behind the farrowing crate in order to obtain a good view and to determine the birth of the first piglet. Cameras were connected to a Digital Video Recorder (TP-S1016DR, Topica, Taiwan), which stored the images on a hard disk.

6.8 Statistical analysis

Statistical analysis was performed using SPSS statistical software versions 13.0 and 15.0 for Windows (SPSS[®] Inc., Chicago, Illinois, USA).

6.8.1 Analysis of variance (ANOVA) / Chi-square test

Analysis of variance (ANOVA) with repeated measurements (GLM repeated measurements) was carried out in studies I, II and III. In studies I and III, the main within-subject factors were periods (Gill and Hafs, 1971). In study III,

feeding treatments were included as between-subject factors, whereas in study I, housing (CRATE vs. PEN) represented the main between-subject factors. In study II, the within-subject factors for the photocell sensor were the mean duration of standing or the mean frequency of getting up and lying down for all 24-h intervals before and after farrowing. The within-subject factor for the force sensor was the mean frequency of peaks exceeding 0.1 V for all 24-h intervals before and after farrowing.

In study III, causes of piglet mortality and the incidence of different grades of constipation were subjected to the Chi-square test as frequency variables.

6.8.2 Multivariate analysis

Linear regression was used to study the effect of multiple factors on piglet weight gain (III).

In study IV, the duration of farrowing and the piglet birth interval were the dependent variables tested for the effect of multiple factors. In both studies, all factors that approached significance ($P < 0.1$) were included as independent variables in a multivariate analysis. Non-significant variables ($P > 0.1$) were excluded from this multivariate model. In study IV, a \log_{10} transformation was performed for the variables of duration of farrowing and piglet birth interval in order to account for the normal distribution.

7. RESULTS

This section summarises some of the results obtained in the four studies (I-IV). A more detailed description of all the results can be found in each of the published papers included in the last section of this thesis.

7.1 Effect of housing on farrowing-associated hormonal parameters (I)

Sows housed in crates (CRATE) showed a higher salivary cortisol concentration than did sows in pens (PEN) in frame period B from two to five days after farrowing ($p < 0.05$). In the PEN group during period B, cortisol returned to its pre-farrowing concentration, but remained higher in the CRATE group ($p = 0.03$; Fig. 7).

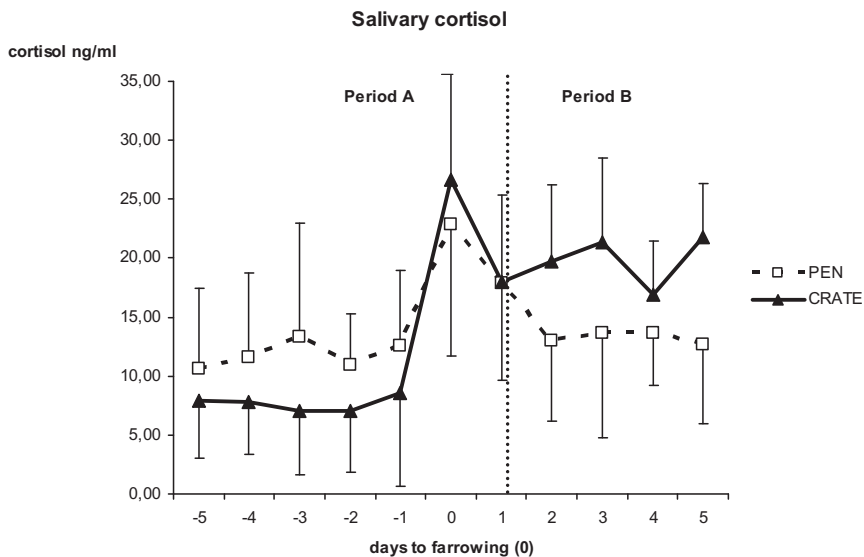


Figure 7. Average salivary cortisol concentration in the PEN (▲) and CRATE (□) groups. Results appear as a mean \pm SD.

The average post-expulsion oxytocin pulse concentration (measured within 6 min after the piglet's expulsion) for the CRATE sows tended to be lower (38.1 ± 24.6 pg/ml; $n = 9$) than that for the PEN sows (77.6 ± 47.6 pg/ml; $n = 9$; $p = 0.08$; Fig. 8). The duration of farrowing was strongly associated with the oxytocin values ($p < 0.001$). In addition, without taking into consideration the two different treatments, sows with a duration of farrowing longer than 4 h

(n = 10) had an average post-expulsion oxytocin pulse concentration of 26.6 ± 21.2 pg/ml, and those with a duration of farrowing shorter than 4 h (n = 8) had an average post-expulsion oxytocin pulse concentration of 82.8 ± 37.7 pg/ml (p = 0.002).

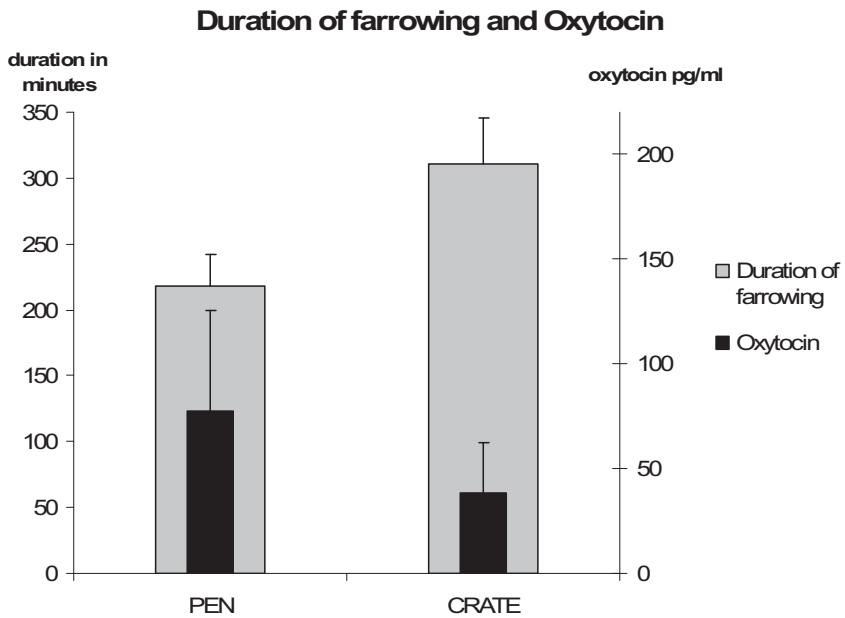


Figure 8. Average duration of farrowing and average Oxytocin post-expulsion pulses in the PEN (n = 9) and CRATE (n = 9) groups of sows (mean \pm SD).

7.2 Factors affecting the duration of farrowing (I, IV)

7.2.1 Housing and its effect on the duration of farrowing and piglet mortality

The duration of farrowing was on average 89 to 93 min longer in the CRATE sows than in the PEN sows ($p < 0.05$; Table 2). The number of stillborn piglets in studies I and IV are summarised in Table 3.

Table 2. Duration of farrowing

Housing	Study I		Study IV		TOTAL
PEN	218 ± 24	(n = 19)	212 ± 94	(n = 57)	(n = 76)
CRATE	311 ± 35	(n = 15)	301 ± 165	(n = 115)	(n = 130)
	P < 0.05		P < 0.05		

Table 3. Stillborn piglets (n = litters)

Housing	Study I		Study IV		TOTAL
PEN	1.0 ± 1.2	(n = 20)	0.4 ± 0.7	(n = 57)	(n = 77)
CRATE	1.1 ± 1.3	(n = 18)	1 ± 1.5	(n = 115)	(n = 133)
	P > 0.05		P < 0.01		

Without considering the treatments, sows with a duration of farrowing longer than 300 min had 1.3 ± 1.3 (mean ± SD) stillborn piglets in study I, and 1.5 ± 1.8 stillborn piglets in study IV, whereas sows with a duration of

farrowing shorter than 300 min had 0.6 ± 1.0 stillborn piglets in study I, and 0.4 ± 0.8 stillborn piglets in study IV ($P < 0.001$).

7.2.2 Body condition and constipation

In study IV, the average back-fat value was 14.5 ± 3.6 mm (range from 7.5 to 24.5, $n = 172$); higher back-fat values negatively affected the duration of farrowing ($p < 0.001$). In Figure 9, all the sows in areas C and D have normal durations of farrowing (< 300 min), whereas those in areas A and B farrowed longer than normal (> 300 min). Most of the fatter sows (> 17 mm of back fat) were in area B, whereas most of the thinner sows (< 17 mm of back fat) were in area C.

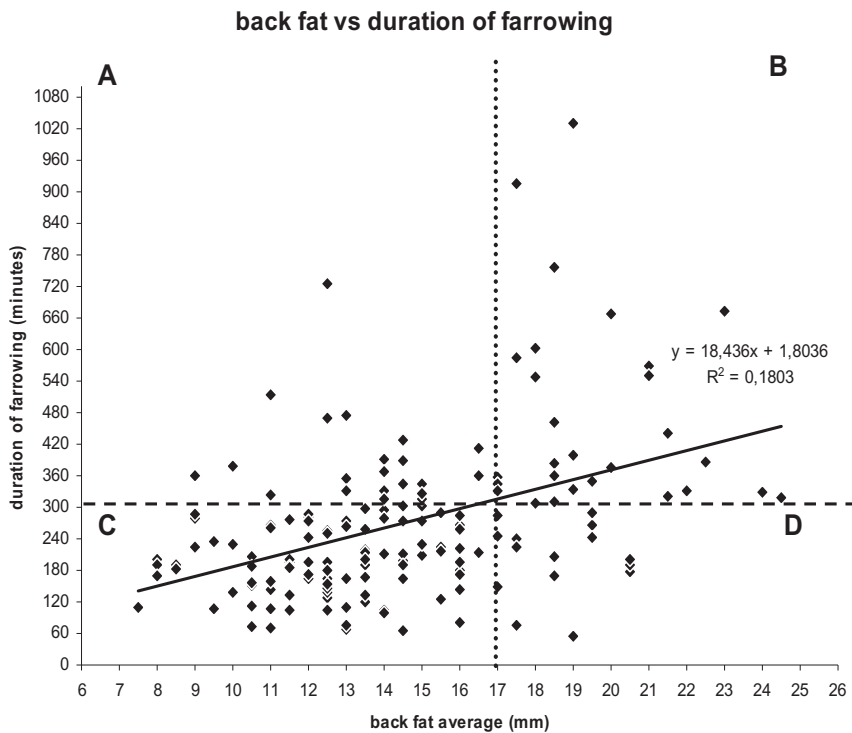


Figure 9. Individual sows plotted according to back-fat average and the duration of farrowing. The horizontal dashed line distinguishes prolonged farrowing (> 300 min; areas A, B). The vertical dotted line distinguishes the fatter sows (areas B, D). The solid regression line represents a positive relationship between the back-fat average and the duration of farrowing.

The average constipation index score was 2 ± 0.6 (range 0.3 to 3, $n = 172$); the lower constipation index scores negatively affected the duration of farrowing ($p < 0.01$). Figure 10 shows that all the sows in areas C and D have a normal duration of farrowing (< 300 min), whereas those in areas A and B farrowed longer than normal (> 300 min). Many of the constipated sows (< 1.9 CI) were in area A, whereas most of the unconstipated sows (> 1.9 CI) were in area D.

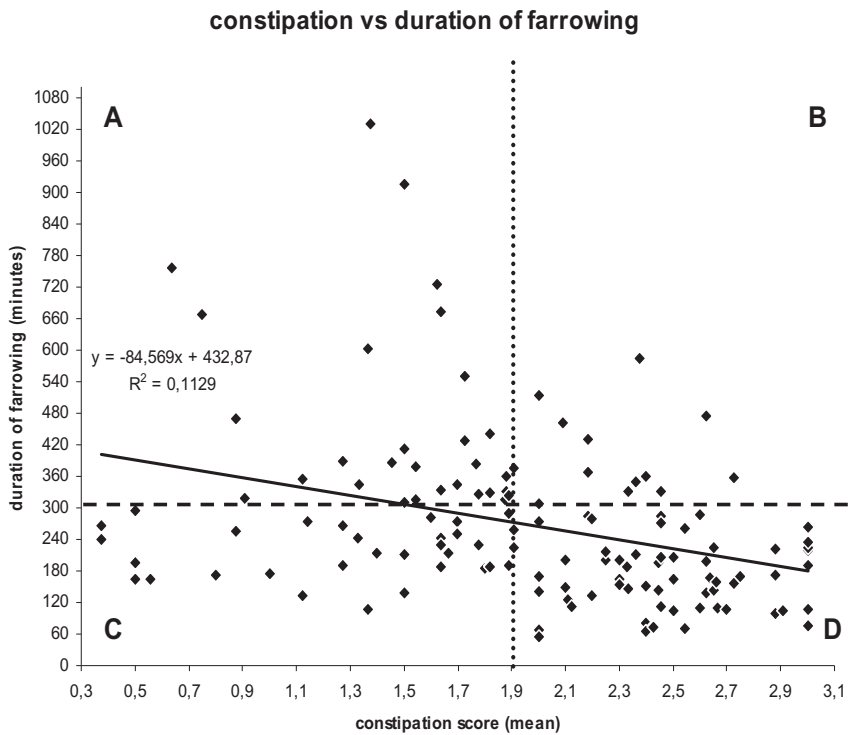


Figure 10. Individual sows plotted according to average constipation index score (CI) and duration of farrowing. Low CI index values indicate constipated sows, whereas high CI values indicate sows with normal faeces. The horizontal dashed line distinguishes prolonged farrowing (> 300 min; areas A, B); the vertical dotted line distinguishes constipated sows (areas A, C). The solid regression line represents a negative relationship between the constipation index and the duration of farrowing.

7.3 Predicting the onset of farrowing using movement sensors (II)

The average duration of standing was significantly longer in the 24-h interval prior to farrowing than in all the other 24-h intervals monitored ($p < 0.05$; $n = 10$; Fig. 11). The mean frequency of getting up and lying down movements was significantly higher in the 24-h interval prior to farrowing than in all the other intervals ($p < 0.05$; $n = 10$; Fig. 11), except for the last two intervals after farrowing ($p > 0.05$). The force sensor recorded a significantly higher number of peaks in the 24-h interval prior to farrowing than in all the other 24-h intervals monitored ($p < 0.05$; $n = 4$).

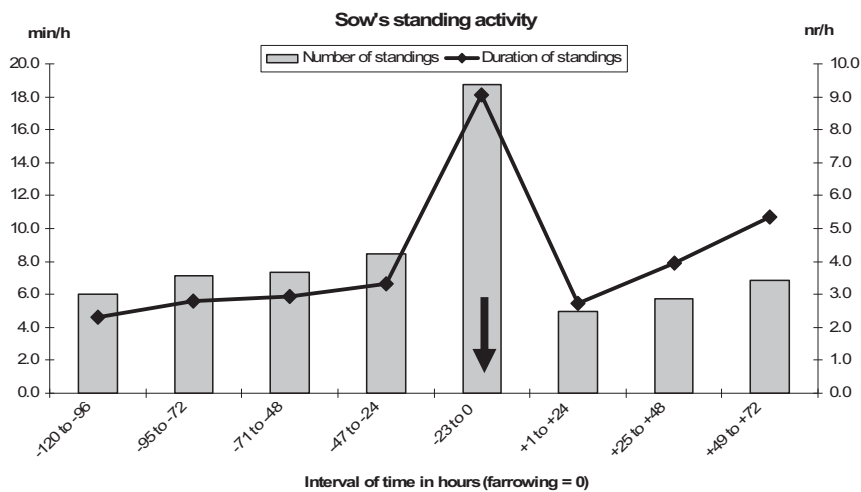


Figure 11. Average duration and number of standings per hour in the different intervals of time before and after farrowing (black arrow).

7.4 Impact of a high-fibre diet on intestinal activity, energy balance-related parameters and litter performance (III).

7.4.1 Intestinal function and water consumption

During the period ranging from five days before to five days after farrowing, we found significant differences in the qualitative scores of the faeces between the two feeding treatments. The sows fed a 7% crude fibre diet (FIBRE) had an average score of 2.1 ± 1.3 (mean \pm SD), whereas the sows fed a 3% crude fibre diet (LACT) had an average score of 1.2 ± 1.1 , $P < 0.001$. Moreover, 22% of the sows in the LACT group exhibited extremely severe

constipation (more than five consecutive days without producing faeces), whereas only 5% of the sows in the FIBRE group exhibited this condition ($P < 0.05$; Fig. 12). The average individual daily water consumption was higher in the FIBRE group ($n = 32$) (29.8 ± 4.9 l) than in the LACT group ($n = 28$) (20.2 ± 3.3 l) ($P < 0.001$).

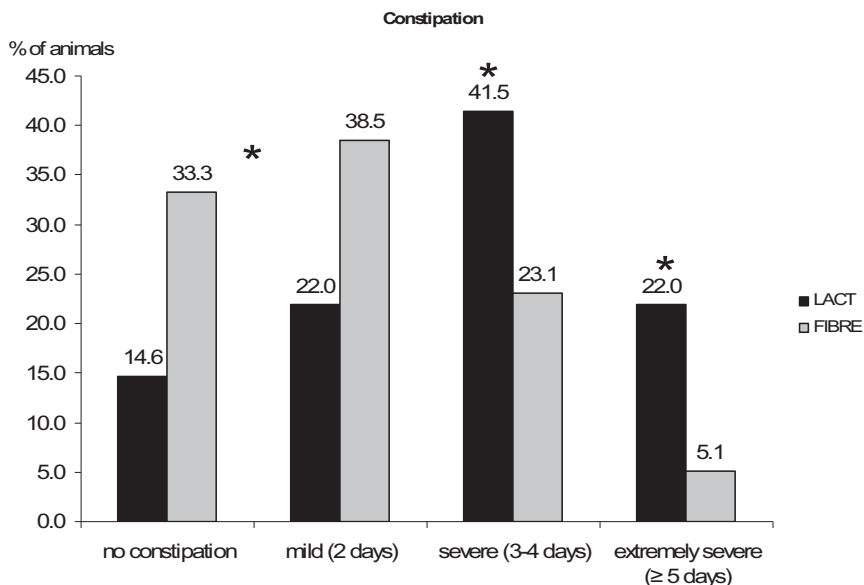


Figure 12. Incidence of different degrees of constipation in the FIBRE ($n = 40$) and LACT ($n = 41$) groups during the observational period (from five days before to five days after farrowing). Asterisks represent significant differences between the two groups ($P < 0.05$).

7.4.2 Energy balance-related parameters: back-fat, NEFA, urea, creatinine, glucose and insulin

No significant differences were found in the blood concentrations of pre- and post-feeding NEFA, insulin and glucose, and pre-feeding urea and creatinine. Only post-feeding urea in the LACT group and post-feeding creatinine in the FIBRE group were significantly higher than in the other group ($p < 0.05$). NEFA peaked at farrowing, indicating a switch in the sow's metabolism to a catabolic state.

7.4.3 Litter performance

On days 1 and 5 of life, the piglets weighed 1.8 ± 0.3 kg and 2.5 ± 0.3 kg in the FIBRE group, and 1.7 ± 0.3 kg and 2.3 ± 0.5 in the LACT group, respectively. The weight gain from day 1 to day 5 of life was significantly higher in the FIBRE group than in the LACT group ($P = 0.04$).

8. DISCUSSION

8.1 Prediction of farrowing improves its supervision

In study II, we demonstrated that movement sensors can be of help in predicting the onset of farrowing. Such sensors are cheap and easy to install in piggeries and would provide farmers with useful information that would help them to better organise and prevent problems at farrowing. Some studies have demonstrated how human supervision at farrowing can drastically reduce the perinatal mortality of piglets (Holyoake et al., 1995; White et al., 1996). Improving the chances of predicting when the sow will give birth would improve the survival of piglets experiencing a dystocic event or suffering from hypothermia or starvation during the first hours after birth. That most sows nowadays farrow without proper assistance in environments that often fail to provide them with the tools they require to express their physiologically driven behavioural needs is indeed unacceptable. More investments are needed to improve the quality of accommodation for farrowing sows and to reduce perinatal mortality due to lack of supervision.

8.2 Housing-related and metabolic considerations on the process of farrowing

We found a significant difference in the duration of farrowing between sows housed in farrowing crates and those housed in pens. A 90-min longer average duration of farrowing increased the number of stillborn piglets. The crate and the absence of an adequate substrate may interfere with the natural expression of the sow's nest-building behaviour and may increase the sow's level of stress at farrowing (Thodberg et al., 1999; Lawrence et al., 1994). High levels of circulating cortisol during farrowing are well documented (Osterlundh et al., 1998.), thus demonstrating that parturition itself triggers a stress-mediated response in the sow. After farrowing, we found a significantly higher level of cortisol in the saliva of crated sows than in penned sows (study I). This could be linked to the prolonged duration of farrowing present in our crated group of sows, which may have impaired their proper recovery. The lack of an environment in which the sow can fully express its nest-building behaviour (Jarvis et al., 2002) contributed to a rise in

the sow's stress level beyond a threshold that may alter other physiological mechanisms as well. The lower level of oxytocin we found in crated sows may explain such an alteration (study I). An insufficient level of oxytocin at parturition may be an important cause of prolonged farrowing, as other studies have also found (Castren et al., 1993).

According to previous findings (Le Cozler et al., 1999), we also found that the metabolism of the sow at farrowing switches to a catabolic state (study III), as the source of energy now comes more from internal reserves (fat and muscles) than from external sources (feed). In this phase, the energy content of the feed seems less important than the quality of the feed itself. Our findings in this study also demonstrated how a state of mild constipation at farrowing can worsen and develop into a severe state of constipation, and thus negatively influencing the duration of farrowing and likely increasing the sow's stress and pain. In our study, cases of severe constipation were avoided by increasing the amount of fibre in the feed served to the sows in the very last phase of the pregnancy. In this phase, due to the sow's high catabolic state, the sow obtains most of its energy from its own body; providing the sow with more fibre in its diet to improve intestinal activity and to reduce constipation is therefore harmless, and may prove more beneficial than providing only concentrated sources of energy. Under this topic, the role of roughage/substrate at farrowing may play an interesting role, because it supports the sow's nest-building behaviour while at the same time may contribute to reduced constipation of the gut by providing the sow with a readily available source of fibre.

8.3 Duration of farrowing and its implications

We found a high correlation between a longer duration of farrowing and a higher number of stillborn, in accordance with other studies (Zaleski and Hacker, 1993; van Dijk et al., 2005). Which of these two factors – a longer duration of farrowing or stillbirth – is the primary cause of the other remains an open question. In our findings (study IV), the sow confined in a crate without bedding material had a longer duration of farrowing and a higher rate of stillbirths. In such a restricted and deprived environment, sows may

experience a disturbance of their nest-building behaviour, with possible consequences being the hormonal cascade generated during this event (Algers and Uvnäs-Moberg, 2007). When the nest-building behaviour is disturbed, the subsequent process of parturition may suffer a delay or slower start because of an altered hormonal pattern. This may imply a higher risk for piglets to asphyxiate in the uterus by remaining there for too long and to experience more dystocic problems resulting from larger piglets born after their due date.

When the duration of farrowing is prolonged, the last piglets to be born will most likely experience more problems due to the longer time they have been under the forces of uterine contractions. Van Dijk et al. (2005) have found that stillborn piglets are delivered after a significantly longer birth interval. Prolonged farrowing may also prove detrimental to sow welfare, because of the prolonged period of labour pain coupled with a possibly slower recovery after an exhaustingly long parturition. A tired sow that experiences difficulty recovering after farrowing may be also less reactive to piglets, thus placing at risk their survival in the first hours after birth.

8.4 Practical implications

The results of our study may encourage farmers to view farrowing more from the perspective of the sow or piglet. The benefits we found for sows farrowing in an open crate are significant and show how the welfare of the animals often correlates positively with economic benefit, as the lower number of stillborn piglets demonstrates. As we have done in our experiments (study IV), it is possible to permit the sow to farrow in an open crate to benefit the most from the better expression of its nest-building behaviour; only after farrowing would the crate need to be closed to eventually protect the piglets from crushing. Adding roughage some days before farrowing would provide the sow with a substrate to better express its nest-building behaviour, and in the case of straw, a possible source of fibre which can alleviate the state of constipation that arises around farrowing.

Constipation at farrowing should be of greater concern to farmers, and our results support the importance of its prevention by increasing the use of fibre in feed during late pregnancy. In addition, looking more carefully for signs of

constipation in the herd can be facilitated with individual daily screening in accordance with our qualitative faecal score. In the farrowing unit, evaluating daily the sow's faeces, especially recording days with no faeces, can provide the farmer and the veterinarian with a clear picture of the individual sow's state of constipation and eventually correct it in time. The sow's intake of drinking water in very late pregnancy, farrowing and lactation is also a very important issue. Some of our findings showed how sows fed a higher-fibre diet drank more water and reared heavier piglets during their first week after birth, confirming how the adequate availability of water during this period is essential (Mroz et al., 1995).

8.5 Implications for the pig industry, such as the supervision of farrowing and housing

Automation is assuming a more and more important role in the management of animal husbandry today. Although, the excessive use of machines and computers to manage the relationship between livestock and humans should be avoided, modern technology can nevertheless be useful in improving the monitoring of physiological, behavioural and clinical signs in production animals – especially given the recent preference of animal production for very large herds with ever larger numbers of animals per unit. An automated system that could monitor the sows in the herd and, with the help of software, sound alarms when appropriate would prove useful indeed. In our experiments (study II), we showed how it is possible to monitor behavioural changes that signal impending farrowing, but it would be similarly possible to monitor important physiological and clinical signs as well. The temperature of newborn piglets is a fundamental issue of survival in their first hours of life (Tuchscherer et al., 2000; Le Dividich and Noblet, 1983). Further investigation on the use of remote devices, such as thermo-cameras, is needed to be able to rapidly and successfully check the body temperature of piglets and sows.

Investments are also needed when planning new herds, and the organisation of the spaces should be considered very carefully. Our findings (studies I and IV) showed how even small modifications in current housing for sows, such as keeping the bars of the farrowing crates open before parturition and providing some bedding substrate, can make a considerable difference in the

welfare of the sows and piglets. Even better results could likely be achieved if housing facilities are planned differently from the beginning and take more into consideration the results of current research on the physiological and behavioural needs of sows in various phases of production.

8.6 Successful farrowing

According to the literature review and the findings of the present work, we define successful farrowing as follows: Assuming that the sow has the tools to properly express its nest-building behaviour, such as the availability of nest-building material and the ability to move freely, and receives a diet that reduces constipation and the risk for obesity, the farrowing of the sow is successful when the total duration of parturition is shorter than 5 h, when more than 90% of the piglets are born alive and survive the following 72 h, and when the sow and piglets experience no complications.

8.7 Future implications and new directions

Hopefully, some of the findings in this study will stimulate further research in the complex field of porcine obstetrics, physiology and behaviour at farrowing. Although we took only a few steps in exploring the use of modern technology to monitor late pregnancy and farrowing in sows, those steps have proved extremely interesting and the findings very promising. Further steps in this field may include research on developing software which would permit monitoring the sows in the herd and updating the information when farrowing is approaching.

The present study was a sort of “hybrid” between a pure experimental model and a field study model. This format was chosen mainly for practical reasons, but also because we believed it would more closely reflect real situations in animal production. We also felt that what we found during our research would be easily applicable to the everyday practice of farmers and veterinarians. Still, confirming our results with a more experimental study design approach would be of considerable interest. Our research explored extremely important and fascinating fields such as the physiology of the porcine uterus and intestine, piglet perinatal mortality and housing structures in production (pens vs. crates). The knowledge in these fields would certainly benefit from wide epidemiological investigations.

9. CONCLUSIONS

1. Sows housed in crates with no nesting material experienced a longer duration of farrowing, a lower concentration of oxytocin during parturition, and a higher number of stillborn piglets than did sows housed in pens with nesting material.
2. Allowing the sow to move freely before and during farrowing, reducing constipation in the sow and avoiding excessive fattening of the sow during late gestation all seemed to be key factors in shortening the sow's farrowing time, and thus reducing perinatal mortality.
3. Photocells and force sensors can reliably measure the activity of crated sows, thereby enabling the development of an automated system for predicting the onset of parturition.
4. Increasing the amount of crude fibre in the diet during late pregnancy and early lactation promoted intestinal function and water intake, thereby reducing drastically the risk for prolonged and severe constipation.
5. Increasing the amount of crude fibre in the diet during late pregnancy and early lactation showed no substantial negative effect on energy balance-related parameters of the sow and early piglet growth.

10. ACKNOWLEDGEMENTS

This research study was carried out at the Department of Production Animal Medicine, Saari Unit, University of Helsinki. It was financially supported by the Finnish Ministry of Agriculture, the Mercedes Zachariassen Foundation, Suomen Rehu Oy and the University of Helsinki. I'm grateful to all of them for making my research possible.

My first contact with the Saari Unit in Finland was during the spring of 2000, when I was an exchange student with the ERASMUS project at the Faculty of Veterinary Medicine. During that experience I was lucky to meet many skilled and highly professional teachers, and among all, my future supervisor Olli Peltoniemi.

To Olli goes all my sincere gratitude to introduce me, years later, in his pig research group, to continuously support me throughout the whole research project, being a solid rock to hold when the mysterious and wild sea of pig research was challenging me. During all these years he has proved to me all his skills in being an excellent teacher, a brilliant scientist and last but not least, a great and loyal friend. Thank You!

I'm also very grateful to my other three supervisors, Mari Heinonen, Outi Vainio and Anna Valros for their support and guidance, and for sharing with me their expertise during this work.

I would like to thank my two pre-examiners, Guy-Pierre Martineau and Bo Algiers, for dedicating their time and for the encouraging words expressed to my work.

My gratitude goes to everyone who contributed to this work, with special thanks to the following persons:

Juha Virolainen for being my tutor in the first steps I took in the field of pig research.

Marjut Vuorijärvi and Pirkko Hämeenoja from Suomen Rehu, for sharing with me their vast knowledge regarding feeding and diseases of pigs.

Marja-Liisa Tasanko at the Saari Unit laboratory, who helped and guided me during my long pipetting days and for her patience when I was filling, with thousand of my samples, any possible space in the freezers of her laboratory.

Satu Sankari, at the central laboratory of the Faculty of Veterinary Medicine, for her supportive help during the biochemistry analysis and for sharing with me her expertise.

All the vet students who helped me during the field work, in sampling the sows, spending with me several days and nights side by side with sows, waiting for the beginning of the farrowings which occurred, of course, mainly during the night.

The farmers Pirjo Poranen, Unto Forsgren, Seppo Tuomi and Jari Ollikkala for allowing me to conduct my studies in their extremely well managed piggeries and for their kind help during many practical issues.

The group of swine researchers at the Saari Unit, Camilla Munsterhjelm, Outi Hälli, Silke Haen, Jonna Oravainen and Eve Ala-Kurikka for sharing fruitful discussions about our field of interest.

Finally I want to thank my wife Lotta for being always supportive and encouraging me when my thoughts about my research were getting confused. My three kids, Cecilia, Filippo and Elena to whom I dedicate this work, hoping one day it can inspire them in their future steps into life.

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