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Parturition effects on reproductive health in the gilt and sow

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Contents

In this review, we address significant characteristics of parturition in the pig and their connection to post-partum reproductive health and fertility. We discuss the normal physiology and behaviour around parturition and the effect of the second phase (expulsion of foetuses) on the third phase of parturition (expulsion of foetal membranes). In addition, we intend to cover retained placenta, and the connection to post-partum uterine health and fertility in the contemporary prolific sow. We also explore factors that support successful parturition or can cause potential problems. Successful parturition in the pig includes the possibility to express adequate maternal behaviour, rapid expulsion of the piglets, complete expulsion of the placenta, neonatal activity and colostrum intake. Abnormal incidents during any phase of parturition can cause subsequent problems. Duration of the expulsion phase of foetuses can be used as a simple measure of whether parturition is considered successful. Prolonged parturition can impair health of the sow and piglet and fertility after weaning. New insights, such as adding more fibre to sow diets during pregnancy, and especially during the period prior to farrowing, may prevent constipation, increase water intake of the sow around parturition and increase milk intake and performance of piglets. Maternal characteristics, including maternal behaviour, ease of parturition, colostrum production and piglet quality parameters, may be utilized to improve success rate of reproductive management during farrowing and early lactation. Additionally, we share some of the recent developments in methods, including ultrasonography in evaluation of post-partum uterine health. In conclusion, successful farrowing is of the greatest importance for reproductive health of the sow and survival of the piglets. We suggest connections exist among prolonged farrowing and yield of colostrum, retained placenta, development of PDS, and impaired involution of the uterus and reduced subsequent fertility.

1 | INTRODUCTION

Reproductive health of the gilt and sow can be defined as the ability to successfully undergo the physiological challenges of the oestrous cycle, mating, pregnancy and lactation. This implies adequate anatomical and physiological resources to complete the challenge of the reproductive cycle without compromising physiological and behavioural needs of the dam or the neonate. Along with increasing litter size, there appears to be demand for welfare-friendly housing systems, which may present a challenge to the producer in terms of reproductive performance of the herd (Einarsson et al., 2014; Kemp &

Soede, 2012; van Nieuwamerongen, Bolhuis, van der Peet-Schwering, & Soede, 2014). There are major setbacks associated with increasing litter sizes that are evident at farrowing, weaning and after weaning, when the foundations of the subsequent pregnancy are laid (Algers & Uvnäs-Moberg, 2007; Martineau, Farmer, & Peltoniemi, 2012). This study addresses some of the key reproductive health problems of the modern hyperprolific sow and her numerous offspring. The problems are encountered at farrowing, early lactation, weaning and beyond, and the problems appear interconnected. When normal physiology and behaviour are compromised around farrowing, not only does the neonate struggle for adequate colostrum. Also, the dam encounters

significant problems with expulsion of placental remnants, involution of the uterus and resumption of ovarian activity. The aim of the review therefore was to discuss current understanding of the relationship between the physiology of farrowing, reproductive health and fertility of the gilt and sow.

2 | PHYSIOLOGY AND BEHAVIOUR OF THE SOW AROUND FARROWING

During early pregnancy, after implantation of the embryos and developmental activity of the *corpora lutea* (CL), high and stable concentrations of progesterone dominate the hormonal pattern (Meulen, Helmond, Oudenaarden, & Van der Meulen, 1988). This ensures the progress of pregnancy, and for almost the whole pregnancy, the circulating concentrations of progesterone remain high. One of the key functions of progesterone is to inhibit contractions of the myometrium during pregnancy. At approximately 24–48 hr before the beginning of parturition, activation of the pituitary adrenal axis of the fetuses heralds the end of CL of pregnancy associated with the quick drop in progesterone concentration. At this time, progesterone is metabolized into estradiol. The removal of this hormonal quiescence factor blocking uterine contractions also known as “progesterone block” by activation of the pituitary adrenal axis is supported by peaking prostaglandin $F_{2\alpha}$ concentration of uterine origin. The change in the steroid balance activates oxytocin receptors, and thereby myometrial activity, as increasing oxytocin concentrations bind to their receptors (Taverne & Noakes, 2009; Taverne & van den Weijden, 2008). Prolactin concentration gradually increases prior to farrowing (Anderson, 2000; Ellendorff et al., 1979; Kindahl, Alonso, Cort, & Einarsson, 1982; Osterlundh, Holst, & Magnusson, 1998). The activation of neural receptors by suckling piglets at the mammary gland stimulates oxytocin secretion from the posterior pituitary and prolactin, growth hormone, ACTH and thyroid-stimulating hormone from the anterior pituitary. These hormones promote milk production mainly through promoting milk synthesis in the mammary tissue and let down into the alveoli and lactiferous ducts of the udder (Martineau et al., 2012).

The first stage of farrowing includes dilatation of the cervix, a complex biochemical process involving cytokines, prostaglandins, peptide (relaxin) and steroid hormones (Taverne & Noakes, 2009). A concomitant increase in well-coordinated myometrial contractions is characterized as a response to the increased oxytocin activity in the presence of the changed steroid environment. The second stage of labour in the sow involves straining of the dam in recumbent posture, rupture of the allantochorionic sac and expulsion of fetuses. In the modern sow, the average duration of this stage appears to be approximately 4 hr with a 20-min interval between fetuses born (van Dijk, van Rens, van der Lende, & Taverne, 2005; Gu et al., 2011; Oliviero, Heinonen, Valros, Hälli, & Peltoniemi, 2008). During the third stage of farrowing, uterine contractions persist in a peristaltic manner, high in frequency but lower in amplitude as compared with the second stage. During this stage, the foetal membranes are expelled in a process that should take no longer than 4 hr (Taverne & Noakes, 2009). Retention of the

placenta can be classified as (i) primary placenta retention—no placenta was expelled within the observation of 24 hr after the last piglet, (ii) primary partial placenta retention—some placenta was expelled during parturition and no placenta is expelled after the last piglet within the observation of 24 hr after the last piglet and (iii) secondary placenta retention—expulsion of the last placenta more than 4 hr after expulsion of the last piglet.

Sows approaching farrowing isolate themselves from the rest of the group at approximately 24 hr prior to farrowing and have an innate need to build a nest where the litter is born (Jensen, 1986; Jensen & Redbo, 1987). This nest-building behaviour is characterized by collecting branches, leaves or grass and by rooting and pawing activity (Jensen & Redbo, 1987). The behaviour starts within 24 hr before the birth of the first piglet, is expressed with highest activity 3–8 hr before the birth of the first piglet and should gradually end prior to the birth of the first piglet (Hartssock & Barczewski, 1997; Westin, 2014). It has been argued that the need of the sow to build a nest might have disappeared during domestication, breeding and confinement of sows in modern farrowing crates, but an increasing body of evidence suggests that the modern sow has just as much of need and ability for nest building as her ancestor, the European wild boar (Algers & Uvnäs-Moberg, 2007; Gustafsson, Jensen, de Jonge, Illman, & Špinko, 1999; Oliviero, Heinonen et al., 2008).

Modern housing systems have promoted the confinement of sows in crates during farrowing, whereby the sow is allowed very limited movement and bedding, and nest-building substrate is often absent or very limited as well (Cronin, Simpson, & Hemsworth, 1996; Edwards & Fraser, 1997; Gu et al., 2011; Jensen et al., 1997; Thodberg, Jensen, Herskin, & Jørgensen, 1999; Vestergaard & Hansen, 1984). The restricted movement of the sow by confinement in a cage has been motivated by reduced mortality of the neonatal piglets (Hales, Moustsen, Nielsen, & Hansen, 2014; Hansen & Curtis, 1980). In these conditions, the nest-building behaviour as triggered by endogenous hormonal activity cannot be properly expressed. In the absence of a nest-building substrate, confined sows express prolonged and unsuccessful nest-building behaviour (Damm, Vestergaard, Schröder-Petersen, & Ladewig, 2000; Damm, Lisborg, Vestergaard, & Vanicek, 2003; Yun et al., 2014; Yun, Swan, Oliviero, Peltoniemi, & Valros, 2015). The stress is characterized by lower oxytocin concentration during the process of parturition, behavioural abnormalities and maintenance of cortisol concentration at a high level after parturition (Jarvis, Reed, Lawrence, Calvert, & Stevenson, 2002; Lawrence et al., 1994; Oliviero, Pastel et al., 2008). Prolonged duration of farrowing is considered as one of the complications of the confinement stress (Oliviero, Heinonen, Valros, & Peltoniemi, 2010).

The lack of opportunity to express appropriate nest-building behaviour can lead to increases in circulating cortisol and ACTH (Jarvis et al., 1997), which indicate a stressful condition. Gustafsson et al. (1999) reported 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 indication of impending farrowing and is present regardless of housing or availability of bedding material.

One of the triggering factors for nest-building behaviour is a rise in prolactin level (Castrén, Algers, De Passillé, Rushen, & Uvnäs-Moberg, 1994), induced by a decrease in progesterone and an increase in prostaglandins (Algers & Uvnäs-Moberg, 2007). Increase in oxytocin secretion in a rapid pulsatile manner, in turn, appears to stop nest-building behaviour a few hours prior to the birth of the first piglet. Prolonged nest-building behaviour, which may still continue during parturition, is considered abnormal and indicative of problems in the hormonal processes of parturition (Algers & Uvnäs-Moberg, 2007).

In conclusion, the onset of parturition with adequate nest-building behaviour of the sow is under strict endogenous hormonal control. The benefits of using pens and enrichment for free farrowing, making nest building possible, are significant and support normal reproductive physiology of the gilt and sow and support their behaviour prior to and during farrowing.

3 | EFFECT OF PARTURITION AND NEST-BUILDING BEHAVIOUR IN EARLY LACTATION

The mammary gland develops during the last third of gestation, with the accumulation of colostrum brought on by the initiation of farrowing and let down already 12 hr before the birth of the first piglet. This process is guided by pituitary peptide hormonal activity, including prolactin and oxytocin (Martineau et al., 2012). The first milk ejections can therefore appear before farrowing starts or at latest when it is completed (Algers & Uvnäs-Moberg, 2007). During the first hours of parturition, colostrum is readily available almost continuously, but any further release of colostrum requires suckling stimulus and a release of oxytocin (Fraser, 1984). This early milk ejection is favourable for prompt and adequate support to the newborn piglets, and it is strictly correlated with the pre-partum behaviour of the sow, driven by decrease in blood progesterone and increase in circulating prolactin and oxytocin (Algers & Uvnäs-Moberg, 2007). Maternal behaviour in free-ranging sows is normally exercised in a nest isolated from the rest of the group that the sow has built during the pre-parturient period (Jarvis, Reed, Lawrence, Calvert, & Stevenson, 2004). Some hours before farrowing sows show natural nest-building behaviour, such as foraging, rooting and pawing, expressing the desire to build a shelter for protecting their offspring. However, the possibility to perform these natural activities in farrowing crates is limited because of lack of space, material or both. Provision of a biologically relevant stimulus, such as straw, positively affects not only the nest-building behaviour prior to farrowing, but also the nursing and suckling behaviour of sows and piglets. This reduces occasions when sows terminate suckling and frequency of foreleg rowing. It also increases the time the piglets spend suckling and triggers an earlier development of suckling behaviour, which are advantageous for early milk intake by piglets, including the piglets with low birthweight (Herskin, Jensen, & Thodberg, 1999; Loisel, Farmer, Ramaekers, & Quesnel, 2014). Farrowing crates appear to prohibit interactions between the sow and her piglets to some extent, and the provision of space during parturition could facilitate

the performance of maternal behaviour. A balanced hormonal pattern at farrowing appears to be important not only for parturition, but it might continue during early lactation. Unlike cows, sows have no teat cisternae, which is why a piglet cannot obtain milk without there being an increase in the intramammary pressure mediated by oxytocin release (Algers & Uvnäs-Moberg, 2007). Sows kept in farrowing crates with no nest-building material tended to have lower oxytocin concentrations during farrowing than sows kept in loose-housed pens with abundant nest-building materials (Oliviero, Heinonen et al., 2008). In the same study, the sows with lower oxytocin concentration had also longer duration of farrowing, which was in accordance with a previous study where sows with long farrowing times had lower basal and lower peak levels of oxytocin during farrowing in comparison with sows with short farrowing times (Castrén, Algers, De Passillé, Rushen, & Uvnäs-Moberg, 1993). Recent results show that events affecting the sow immediately before and during farrowing can also affect early lactation. A plentiful supply of nesting materials prior to parturition leads to an increase in sow plasma oxytocin and prolactin concentrations from 3 days prior to parturition until 7 days post-partum (Yun et al., 2013). This indicates a potential association between nest-building possibilities induced by abundant nesting materials and circulating oxytocin and prolactin concentrations in peripartal sows. In this study, however, sows housed in loose pens with limited nesting materials did not have higher oxytocin concentrations than sows in confined farrowing crates with an equally limited amount of nesting materials. This indicates that abundant nesting materials may make a greater contribution to increased oxytocin concentrations than non-confinement in loose-housed pens (Yun et al., 2013). In the same study, farrowing housing in crates required extra udder stimulation by the piglets to obtain milk in the early lactation period (Yun et al., 2013). This prolonged udder massage might disturb the sow because it cannot be avoided in the crate, likely resulting in poor welfare because of inadequate coping mechanisms of the sow to such prolonged stress caused by the piglets. Indeed, Oliviero, Heinonen et al. (2008) found a higher concentration of salivary cortisol of sows in crates, when compared with sows in pens for loose housing. He suggested that this was caused by the sows having difficulties in denying their offspring from nursing (Fig. 1). When sows are provided with abundant nesting material, they show a greater incidence of careful pre-lying behaviour and appear to perform better maternal behaviour in order to care for their offspring (Yun et al., 2013). Therefore, provision of adequate space and nesting material before parturition can improve sow welfare by providing opportunities for sows to express their normal behaviour, reduce farrowing duration and stillbirth rate, and also reduce potential stresses during the early nursing period. This last progressive effect is of great importance because the conclusion of farrowing is not the terminal point of a successful parturition. At this point, if the sow is unable to produce an adequate amount of colostrum to satisfy the newborn piglets, it will dramatically affect their survival. The influence of the litter on the colostrum production seems smaller than it would be during the rest of the lactation. Piglets fed colostrum *ad libitum* were able to take in up to 450 g/kg birthweight, which is double what piglets can consume in normal conditions (Devillers, Van Milgen,

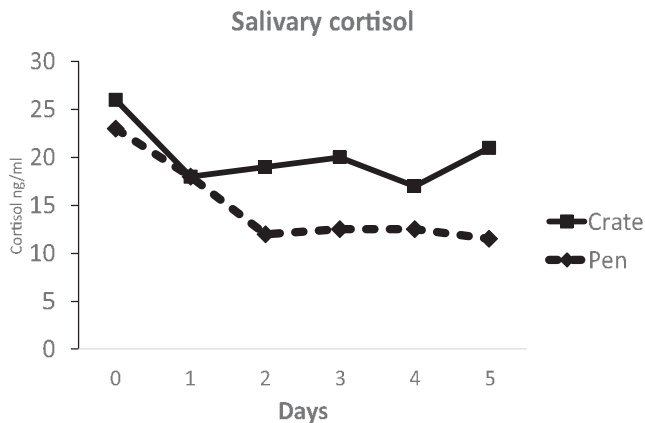


FIGURE 1 Salivary cortisol average concentration in the pen-housed sows and in the crate-housed sows. Day 0 is the farrowing day. (Oliviero, Heinonen et al., 2008)

Prunier, & Le Dividich, 2004). Colostrum yield averages approximately 3.5 kg, but there is substantial variation among sows, with a range from 1 to 6 kg (Devillers, Farmer, Le Dividich, & Prunier, 2007; Quesnel, 2011). Colostrum yield is less correlated to litter size than the birthweight (Devillers et al., 2007; Quesnel, 2011). Colostrum is freely available during parturition, and regular suckling by piglets is necessary to maintain its secretion in the first 24-hr post-partum and beyond (Theil et al., 2006). Therefore, the availability of colostrum is more connected to the vitality of piglets and mostly with the capacity of the sow to produce colostrum (Quesnel, Farmer, & Theil, 2015). Foisnet, Farmer, David, and Quesnel (2010) established that gilts producing a low yield of colostrum (1.1 kg) had greater concentrations of progesterone and lower concentrations of prolactin before farrowing, and at the onset of farrowing, compared with the high-producing gilts (3.9 kg). This was confirmed by Quesnel et al. (2015), where a low ratio of prolactin to progesterone before and during farrowing affected colostrumogenesis and piglet survival negatively. In several studies, there was no clear-cut effect of duration of parturition on colostrum yield established (Declerck, Dewul, Piepers, & Decaluwé, 2015; Devillers et al., 2004; Foisnet et al., 2010; Quesnel, 2011). Therefore, instead of a prolonged duration of farrowing, a low colostrum yield may be attributed to hormonal dysfunction. In conclusion, promoting better nest-building behaviour before farrowing might be beneficial not only for better progression of parturition but also to promote adequate colostrum yield.

4 | EFFECT OF FARROWING DURATION ON PLACENTA EXPULSION

The second phase, foetal expulsion, is followed by the last phase of parturition, detachment and expulsion of the placentae. The placenta is supposed to be expelled within 4 hr after the birth of the last piglet (Taverne & Noakes, 2009). Surprisingly, the duration of placenta expulsion has only been reported twice, once in sows (Jones, 1966) and once in gilts (van Rens & van der Lende, 2004). Jones (1966)

reported a duration of 4 hr and van Rens and van der Lende (2004) of approximately 2.5 hr. One of our field studies in sows (Björkman et al., unpublished) showed an average duration of placenta expulsion of 4.5 hr. In the study of van Rens and van der Lende (2004), gilts had an average farrowing duration of 2 hr and an increase in duration of farrowing was significantly associated with an increase in duration of placenta expulsion. In our study (Björkman et al., unpublished), a similar association was found, but only in sows with a farrowing duration of <7 hr. Interestingly, duration of farrowing and placenta expulsion obeyed a quadratic rather than a linear relationship. In sows with a short farrowing duration (<7 hr), placenta expulsion duration increased with increasing farrowing duration, whereas in sows with a prolonged farrowing duration (>7 hr), placenta expulsion duration decreased with increasing farrowing duration. Furthermore, we observed sows that had a partial primary placenta retention (3% of 149 sows) and sows that had a complete primary placenta retention (3% of 149 sows). Sows with partial primary retention had an average farrowing duration of 11 hr, and sows with total primary retention had an average farrowing duration of 17 hr (Björkman, Peltoniemi, Oliviero, & Soede, 2015). The observation suggests that sows with extremely prolonged farrowing duration have reduced placenta expulsion. Secondary uterine inertia, which causes insufficient expulsive force of the uterus, could be one explanation, which is supported by Oliviero, Heinonen et al. (2008), who showed that increased farrowing duration is associated with decreased oxytocin levels. In addition, this is supported by the observation that moderate use of oxytocin injections towards the end of the second phase of the parturition had a significant effect in reducing the duration of placenta expulsion in sows with short farrowing duration ($n = 68$). On the other hand, oxytocin administration increased the duration of placenta expulsion in sows with prolonged farrowing duration ($n = 74$ Björkman et al., unpublished). Sows that received oxytocin and with farrowing durations of approximately 20 hr were able to expel their placenta after the last piglet, whereas sows with the same farrowing duration that received no oxytocin experienced primary placenta retention (Björkman et al., unpublished).

Thus, the primary placenta retention seems to be linked with a long farrowing duration. The secondary placenta retention, on the other hand, seems to be linked to a short farrowing duration. In our study, 6% of the sows expelled the last placenta only after 12 hr, 37% after 4–12 hr and only 51% within 4 hr after the birth of the last piglet (Björkman, Peltoniemi et al., 2015). These sows had farrowing durations of 4.5, 6 and 7 hr, respectively.

Another interesting and highly significant difference between sows with short and prolonged farrowing durations is the onset of placenta expulsion. In sows with a short farrowing duration, placenta expulsion starts on average one hour after the birth of the last piglet. In contrast, in sows with prolonged farrowing duration, placenta expulsion starts on average one hour before the birth of the last piglet (Björkman et al., unpublished). This information could be used on the farm as an indicator of a sow at risk of experiencing prolonged farrowing. If piglets are born after expulsion of placenta, it is likely that the sow has been in labour for more than 7 hr. Therefore, oxytocin might be used to support

the placenta expulsion and post-partum care of the sow, to prevent post-partum diseases and reduced subsequent fertility.

In conclusion, farrowing duration seems to have an impact on placenta expulsion. In gilts, a linear correlation was established (van Rens & van der Lende, 2004), whereas in sows, a quadratic relationship pertained (Björkman et al., unpublished). This suggests that sows with prolonged farrowing duration might suffer from secondary uterine inertia. Furthermore, oxytocin has a strongly positive effect on placenta expulsion. If sows with extremely long farrowing durations are treated with oxytocin, they seem still to be able to expel the placenta. However, sows that are not treated with oxytocin might undergo primary placenta retention.

5 | EFFECT OF PARTURITION ON POST-PARTUM UTERINE HEALTH AND POST-PARTUM DYSGALACTIA SYNDROME

Post-partum dysgalactia syndrome (PDS) is characterized by insufficient colostrum and milk production during the first days after farrowing (Martineau et al., 2012). It is considered to be a multifactorial disease involving different pathways, one of which is mediated by endotoxins produced by bacteria in the gut, bladder, mammary gland or uterus (Martineau et al., 2012).

The effect of parturition on the occurrence of PDS has rarely been investigated. In a recent study by Tummaruk and Sang-Gassanee (2013), the percentage of sows with fever during the first 24-hr post-partum increased from 40 to 100% when the farrowing duration increased from <2 to 4–8 hr. This finding suggests that good farrowing management and quick piglet expulsion are important for the post-partum health status of the sow. There is little information available about whether and how parturition affects post-partum disorders. There seems to be a connection between prolonged farrowing duration and post-partum disorders such as PDS; for example, both have common risk factors: constipation (Hermansson, Einarsson, Larsson, & Backstrom, 1978; Martineau, Smith, & Doize, 1992; Oliviero, Kokkonen, Heinonen, Sankari, & Peltoniemi, 2009); increased back fat (Göransson, 1989; Oliviero et al., 2009); no farrowing supervision (Papadopoulos, Vanderhaege, Janssens, Dewulf, & Maes, 2010; Björkman et al., unpublished); restricted space in crates at farrowing (Bäckström, Morkoc, Connor, Larson, & Price, 1984; Cariolet, 1991; Oliviero, Heinonen et al., 2008); and farrowing induction (Papadopoulos et al., 2010; Smith, 1982). In the study by Tummaruk and Sang-Gassanee (2013), a connection between farrowing duration and post-partum fever was established, but not for farrowing duration and PDS. However, PDS was defined according to the presence of udder inflammation and/or agalactia. Thus, only a small proportion of the complex clinical signs (Martineau et al., 2012) has been investigated. To the knowledge of the authors, no study to date has investigated the impact of farrowing duration on uterine health and occurrence of endometritis, which plays an important role in the development of PDS (Martineau et al., 2012). It is feasible to assume that prolonged parturition affects uterine health. During prolonged

parturition, the physical barrier against bacterial invasion, the cervix, is open for a long time. As discussed above, prolonged duration can cause placental retention (Björkman et al., unpublished). The placenta represents a perfect medium for ascending bacteria. Furthermore, prolonged farrowing duration seems to be one of the causes of secondary uterine inertia, which is due to exhaustion of uterine muscles and not due to ability to contract (primary uterine inertia). In prolonged parturition, the uterine clearance appears therefore to be compromised (Oliviero, Heinonen et al., 2008). Therefore, our research group made an effort to assess the uterus after parturition (Björkman, Oliviero, & Peltoniemi, 2015). The assessment was performed 3 days *post-partum* using transabdominal ultrasonography (Fig. 2), and the image area of the uterus was categorized as small ($n = 61$; Fig. 2) or enlarged ($n = 46$; Fig. 3). Transabdominal ultrasound examination appears to be the only reliable method (Kauffold et al., 2005) because sows with uterine



FIGURE 2 Representative image of a sow with a uterine horn already well in the process of involution 3 days post-partum (p.p.). The normal range of the image area between 2 and 7 days p.p. was 4–3 cm², respectively (Björkman, Oliviero et al., 2015). This sow had a successful farrowing, no dystocia nor birth help



FIGURE 3 Representative image of a sow with a delayed involution of the uterine horn 3 days post-partum. This sow had an unsuccessful farrowing of more than 5 hr. The normal range of the image area between 2 and 7 days p.p. was 3–4 cm², respectively (Björkman, Oliviero et al., 2015)

inflammation, such as endometritis, may not exhibit clinical signs such as vaginal discharge (Dalin, Gidlund, & Eliasson-Selling, 1997; de Winter, Verdonck, de Kruif, Devriese, & Haesebrouck, 1995). We investigated the correlation between farrowing duration, dystocia (time between two piglets more than 60 min), placenta expulsion duration, total birth duration (time between expulsion of the first piglet and the last placenta), onset of placenta expulsion, primary placenta retention and the effect of application of birth help or oxytocin on size of the uterus. We established significant correlations between farrowing duration, dystocia, total birth duration, application of birth help, primary placenta retention and enlarged uterus. Sows with an enlarged uterus had, on average, 2 hr longer farrowing durations and 2 hr longer total birth durations. Furthermore, sows with an enlarged uterus more often experienced dystocia and needed birth help. All sows with primary placenta retention had an enlarged uterus (Björkman, Oliviero et al., 2015). Interestingly, oxytocin application had a tendency to decrease uterus size. Furthermore, we found a connection between the presence of fluid (Fig. 4) in the uterine lumen and the application of birth help, as well as presence of dense structures in the uterus (Fig. 5) and primary placenta retention. In addition, we observed a connection

between enlarged uterus and heterogeneous echotexture of the uterus (Fig. 3). The same connection was reported earlier in mated sows that failed to conceive and was linked to uterine oedema and inflammation (Kauffold et al., 2005). Fluid accumulation, such as pus, has been associated with uterine inflammation such as endometritis (Martinez, Vazquez, Roca, & Ruiz, 1993), metritis (Botero, Martinat-Botte', & Bariteau, 1986) and pyometra (Knox & Althouse, 1999).

In conclusion, endometritis is considered to be a factor that affects the occurrence of PDS. Only sporadic studies concerning the impact of farrowing on post-partum health (Tummaruk & Sang-Gassanee, 2013) and ultrasonographic investigation focussing on uterine disorders (Kauffold et al., 2005) have been performed. To our knowledge, no study has investigated the effect of farrowing on uterine health. Ultrasonographic investigation seems to be the method of choice. We demonstrated a connection between increased size of uterus and prolonged farrowing duration, total birth duration, birth help and primary placenta retention. Furthermore, birth help has been linked to fluid accumulation and primary placenta retention to dense structures inside the uterus. Kauffold et al. (2005) demonstrated that increased size of the uterus represents uterine oedema caused by inflammation. It therefore seems more than likely that prolonged farrowing duration impairs uterine health.



FIGURE 4 A representative image of a post-partum uterine horn of a sow after prolonged parturition (21 hr) and retained placenta. The structures with increased density/heterogeneity are indicative of retained placenta



FIGURE 5 A representative image of a sow after prolonged farrowing (>5 hr) and repeated dystocia (four times) and birth help (manual removal of piglets). The uterine horn has a high degree of heterogeneity and some fluid visible within the lumen

6 | EFFECT OF FARROWING DURATION AND PDS ON SOW FERTILITY

The complex interactions among environmental effects on the reproductive physiology of sows at farrowing seem to extend beyond lactation to the subsequent fertility of the sow. Recent findings demonstrate that sows with long farrowing duration (>300 min) have a higher repeat breeding rate (Fig. 6; Oliviero, Kothe, Heinonen, Valros, & Peltoniemi, 2013). This finding could provide valuable information for sow reproductive management. There is no clear explanation yet for this interaction. In free-ranging domestic pigs kept in a seminatural environment, weaning of the litter is a slow and gradual process, taking between 91 and 126 days post-partum (Jensen & Recén, 1989). In contrast, in commercial piggeries, the lactation period is relatively short, usually between 18 and 28 days, and the weaning-to-oestrous interval is, on average, 5 days. The interval between parturition and subsequent insemination is therefore much shorter than under natural conditions, which may allow factors that negatively influence the physiology of parturition to interfere at post-weaning oestrus. A complete involution of the uterus takes approximately 14–21 days (Graves, Lauderdale, Kirkpatrick, First, & Casida, 1967; Hays, Krug, Cromwell, Dutt, & Kratzer, 1978; Palmer, Teague, & Venzke, 1965a,b; Svajgr, Hays, Cromwell, & Dutt, 1974). This is supported by the fact that histological involution of the uterus is completed within 3 weeks of farrowing (Belstra, Flowers, Croom, DeGroot, & See, 2005), which underlines the need to prolong the process of weaning beyond day 21 of lactation. As discussed in the previous section, prolonged farrowing duration seems to affect uterine health negatively and increase post-partum uterus size. Increased size of the uterus can be considered as

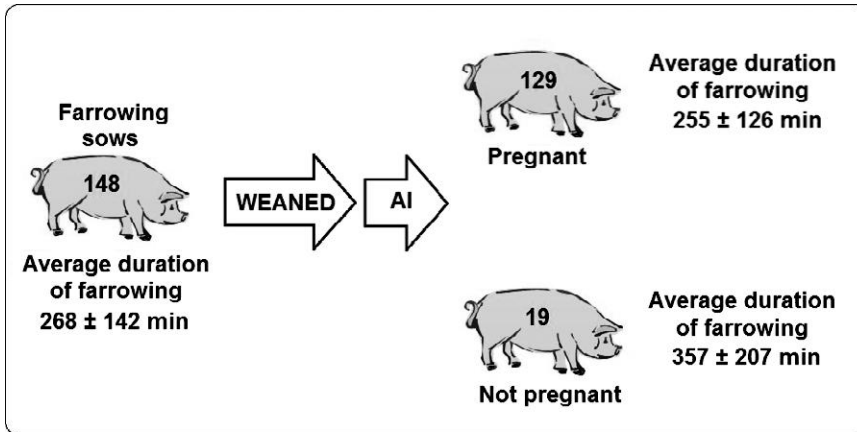


FIGURE 6 Sows that failed to become pregnant at first insemination were having a previous duration of farrowing of 100 min longer than those who became pregnant (Oliviero et al., 2013)

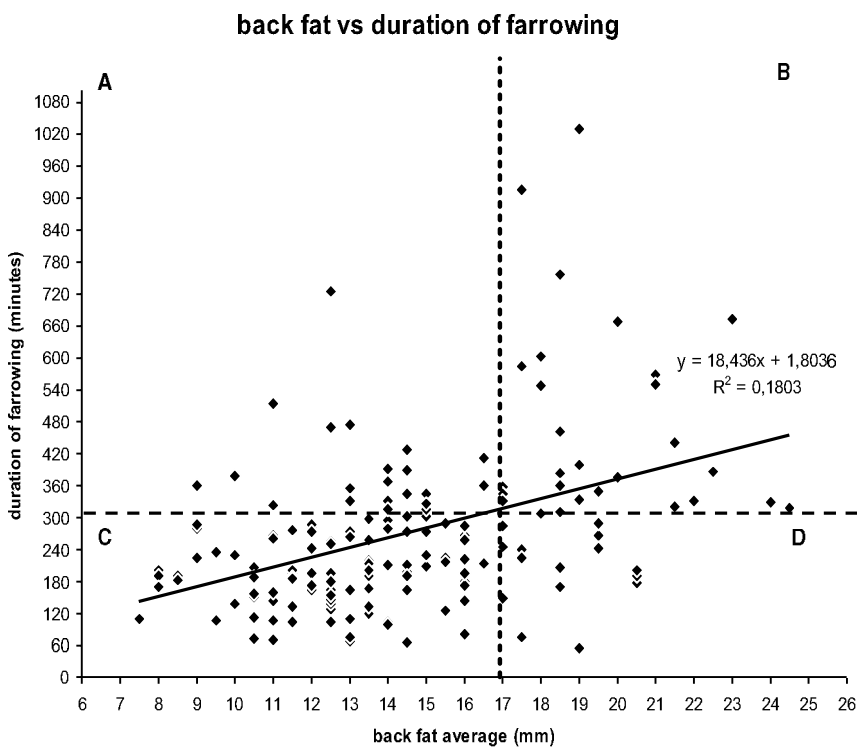


FIGURE 7 Individual sows plotted according to back-fat average and the duration of farrowing. The horizontal dashed line distinguishes prolonged farrowings (>300 min; areas a and b). The vertical dotted line distinguishes the fatter sows (areas b and d). The solid regression line represents a positive relationship between the back-fat average and the duration of farrowing (Oliviero et al., 2010)

swelling due to inflammation (Kauffold et al., 2005). Thus, it may cause, as in other species, that is in beef heifer and dairy cows (Heppelmann et al., 2015; Savc, Kenny, & Beltman, 2016), prolonged uterine involution and thereby interfere with subsequent fertility.

PDS represents another explanation for how prolonged farrowing duration may affect fertility. In a study utilizing a large German database, it was shown that low parity sows suffered more PDS-like symptoms than older sows, with an overall prevalence of approximately 30% (Hoy, 2006). The number of sows not cycling after weaning increased after PDS, the weaning-to-oestrous interval was prolonged, and the repeat breeding rate increased by approximately 4%. In addition, the abortion rate increased as well as the overall mortality of sows (Hoy, 2006). In conclusion, there is at least some evidence to suggest that PDS reduces fertility, not only in terms of reproductive health of the sow and her current neonatal litter, but also subsequent fertility after weaning.

However, further research is needed on uterine involution, follicular development and CL function after breeding. For investigating CL function, we have for the first time described a minimally invasive method that allows tissue collection from the CL. This method, a transvaginal ultrasound-guided biopsy, is rapid, can be performed by one person and has no major effects on the sow's reproductive performance. It can be applied on the farm to study effects on luteal function of housing, management and nutrition (Björkman et al., 2016).

7 | FEEDING THE SOW FOR EASE OF FARROWING

During late pregnancy, one common practice in feeding sows aims to reduce the amount of feed offered and increase the energy of the ration in preparation for the upcoming metabolic changeover into

lactation and farrowing (Farmer, Palin, & Martel-Kennes, 2014; Le Cozler, Beaumal, Neil, David, & Dourmand, 1999). Such concentrated diets usually contain a more limited amount of fibre than do standard gestation diets. This practice aims mainly to ensure that sows receive enough energy during late pregnancy to satisfy upcoming milk production (Decaluwé et al., 2014; Einarsson & Rojkittikhun, 1993). High back-fat values were associated with increased duration of farrowing (Oliviero et al., 2010). In Fig. 7, all the sows in areas C and D had normal durations of farrowing (<300 min), whereas those in areas A and B had farrowings 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. These findings reveal that over condition in the very last part of pregnancy is not recommendable because it could negatively affect the farrowing process and survival of the offspring.

However, there are reports that reducing the volume and fibre content of sow feeds can have negative effects, including increased stereotypic behaviour (Ramonet, Meunier-Salaun, & Dourmad, 1999), the development of gastric ulcers and constipation (Lee & Close, 1987). As sows approach farrowing, mild constipation is common because the intestine is less active approaching parturition (Kamphues, Tabeling, & Schwier, 2000). In addition, water absorption from the intestine increases due to the request for water due to initiation of milk production (Mroz, Jongbloed, Lenis, & Vreman, 1995). Therefore, offering feed low in volume and fibre can worsen constipation and negatively affect milk production. In addition, constipated sows showed higher rates of mastitis than those not constipated, with evidence of a direct effect of constipation on udder health (Hermansson et al., 1978; Persson, 1996). Constipation may also be uncomfortable for the sows, thus impacting their welfare.

Oliviero et al. (2009) found that when sows were fed 7% crude fibre in late pregnancy, their constipation was less severe and they recovered proper intestinal activity faster than those sows fed diets with only 3.8% crude fibre. During the period from 5 days before to 5 days after farrowing, the sows fed a 7% crude fibre diet had an average higher faecal score (less constipation), compared with sows fed a 3.8% crude fibre diet (Fig. 8). The same study revealed that 22% of the sows fed the low fibre diet had extremely severe constipation (more than 5 consecutive days without producing faeces), whereas only 5% of the sows fed the high fibre diet had this condition (Fig. 9). The average individual daily water consumption was also higher in the high fibre group (29.8 ± 4.9 L) than in the low fibre group (20.2 ± 3.3 L) (Fig. 10). Moreover, a high fibre diet fed in late pregnancy until farrowing seemed to improve growth rate of piglets (Oliviero, Heinonen et al., 2008; Quesnel et al., 2009), indicating a positive effect of high fibre diet before farrowing on piglet performance (Oliviero et al., 2009).

Regarding the correlation between faecal score and the duration of farrowing, the average constipation index score was 2 ± 0.6 (range from 0.3 to 3) and the lower constipation index scores (showing more constipation) were negatively related with duration of farrowing (Fig. 11). In conclusion, cases of severe constipation at farrowing can be avoided by increasing the amount of dietary fibre during the

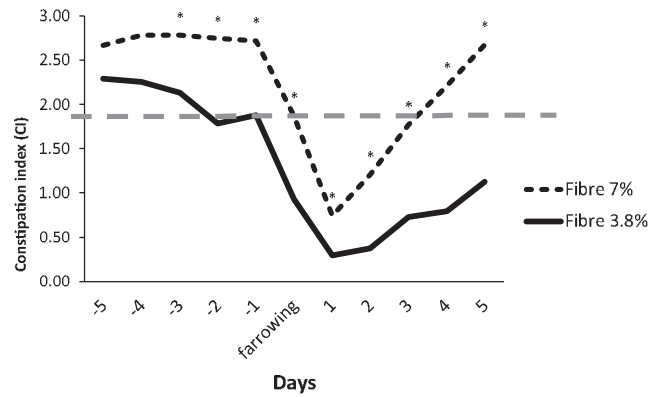


FIGURE 8 Intestinal activity, expressed as constipation index (CI), of sows fed isocaloric diets differing only in crude fibre content. Lower CI values indicate greater constipation state. Normal intestinal activity is considered above the dashed line, CI >1.9 (Oliviero et al., 2009). Significant difference ($p < .05$) is marked with an asterisk

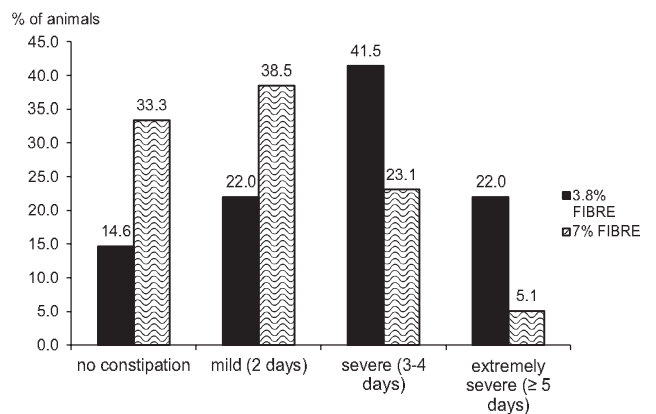


FIGURE 9 Incidence of different degrees of constipation in the sows fed a 7% fibre diet ($n = 40$) and a 3.8% fibre diet ($n = 41$) during the observational period (from five days before to five days after farrowing). Each category considers consecutive days of absence of faeces (Oliviero et al., 2009). Significant difference ($p < .05$) is marked with an asterisk

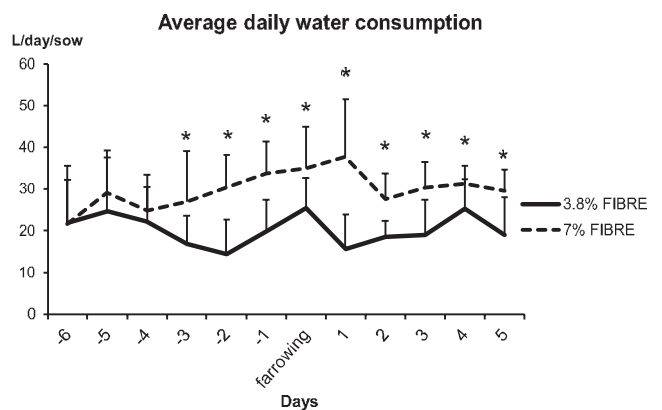


FIGURE 10 Average daily water consumption of sows fed two different levels of crude fibre (Oliviero et al., 2009). Significant difference ($p < .05$) is marked with an asterisk

constipation vs duration of farrowing

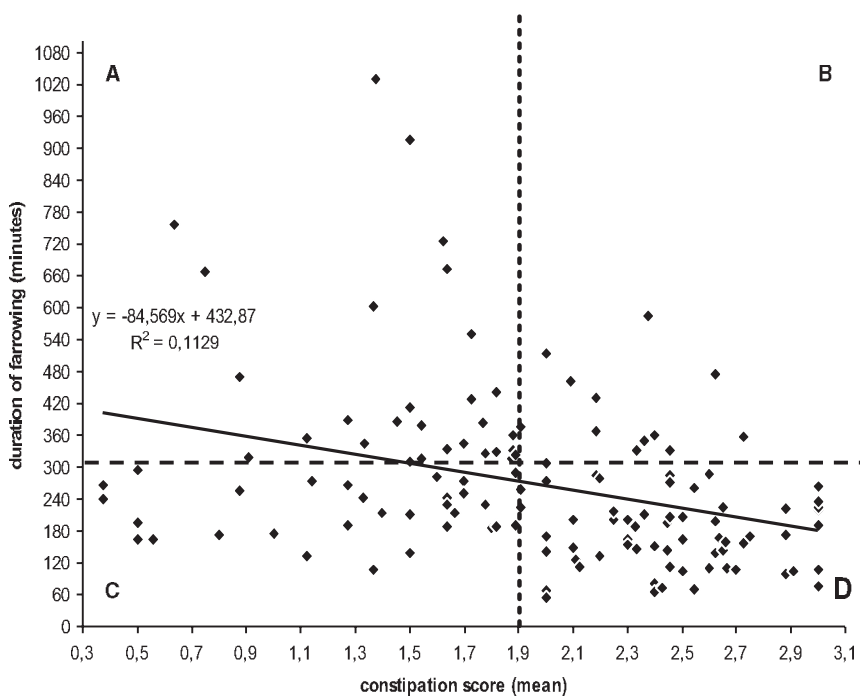


FIGURE 11 Individual sows plotted according to average constipation index score (CI) and duration of farrowing. Low CI values indicate constipated sows, whereas high CI values indicate uncongested sows. The horizontal dashed line distinguishes prolonged farrowings (>300 min; areas a and b); the vertical dotted line distinguishes constipated sows (areas a and c). The solid regression line represents a negative relationship between the constipation index and the duration of farrowing

last phase of pregnancy (Oliviero et al., 2009; Tabeling, Schwier, & Kamphues, 2003). The provision of dietary fibre improves intestinal activity and reduces the degree of constipation. The use of high-fibre diets therefore appears to be a beneficial strategy to improve the health of the sow around farrowing. Giving roughage may not only be a way to increase fibre intake and alleviate constipation, but it can also serve as an appropriate material for nest building.

8 | CONCLUSIONS

There is increasing evidence to suggest that colostrum yield and subsequent fertility are affected by prolonged farrowing, retained placenta, development of PDS and impaired involution of the uterus. These causal factors appear to be correlated to each other in a way not yet fully understood. A prerequisite for successful farrowing is that the sow has the materials and the ability to move freely to express properly her nest-building behaviour. It is important that sows receive a diet that reduces the risk for obesity and incidence of constipation around farrowing. Furthermore, farrowing can be considered successful if the total duration of parturition is a few hours to avoid intrapartum hypoxia of the foetuses. In the contemporary sow, time required for expulsion of placenta appears highly variable and may take more than generally assumed (4 hr). In addition, placenta expulsion should start after the birth of the last piglet. If not, it can indicate that duration of parturition has been too long. Those sows will need attention towards the end of parturition and early lactation. Adequate production of colostrum by the sow and intake by piglets are of fundamental importance to successfully conclude the process of farrowing. Contamination of the birth canal during farrowing and inadequate

management increasing the risk of subsequent inflammation of the mammary gland (PDS) should be avoided. The mechanisms involved in linking farrowing success, uterine health and fertility largely remain to be studied.

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