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Peltoniemi, Olli

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Management practices to optimize the parturition process in the hyperprolific sow

Olli Peltoniemi 1, Claudio Oliviero 1, Jinhyeon Yun 1, Alexander Grahofer 2, and Stefan Björkman
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1 Department of Production Animal Medicine, Faculty of Veterinary Medicine, University of Helsinki, Saarentaus, Finland
2 Animal Physiology, Institute of Agricultural Sciences, ETH Zurich, Switzerland
Correspondence:
Olli Peltoniemi
Department of Production Animal Medicine
Faculty of Veterinary Medicine
University of Helsinki
FI-04920 Saarentaus, Finland
olli.peltoniemi@helsinki.fi

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Abstract

Over the past three decades, efficient breeding and management have almost doubled the litter size of sows. Simultaneously, duration of farrowing has increased markedly. The expulsion phase of parturition in the hyper prolific sow is now 3 to 5 times longer than it was in the early 1990s. There has also been a constant downward trend in piglet birth weight, along with a similar trend in colostrum intake, which is an important risk factor for piglet mortality. Together with these trends, an increase in farrowing complications, such as postpartum dysgalactia and retention of placenta, has been reported. This paper investigates tools and technology to alleviate the problems seen in the hyperprolific sow. In short, the sow needs to be given space and enrichment materials for adequate expression of nest-building behaviour. Diagnostic imaging provides a tool to improve monitoring of physiology and pathology of the female genital tract around parturition. Maternal characteristics may be utilized to improve the success rate of reproductive management during farrowing and early lactation. These include maternal behaviour, such as carefulness and nursing behaviour, ease of parturition, colostrum production, piglet vitality and survival parameters. In feeding, provision of an adequate proportion of high-quality fibre appears to be the best practice in the battle against constipation and obesity. Appropriate management of the sow body condition during the last third of pregnancy is essential for mammary development and colostrum production. Adequate breed selection to facilitate management of sows at farrowing and of piglets during early lactation is also important. Recent findings suggest that management of parturition can affect the immune system and microbiota of newborn piglets. New demands on production, such as an animal-friendly farrowing environment and the heat stress brought about by climate change make it essential to develop breeding strategies for robustness and resilience. The lower piglet birth weight and compromised immunity of newborn piglets warrant investigation in the search for novel management tools. Robust breeds with

somewhat lower litter size, but improved resilience and increased birth weight may be needed in the near future.

Consequences of increased litter size

Over the past three decades, the litter size of most European domestic pig breeds has approximately doubled (Oliviero et al., 2019). In the same period, the average duration of farrowing has extended considerably in those breeds, from a bit more than 2 hours / 12 piglets (Madec and Leon, 1992) to 6 hours 40 minutes / 19 piglets born (Figure 1; Yun et al., 2019) . The difference is even larger if the point of reference is the wild pig with only 5 piglets and a duration of farrowing of just 1 hour 20 minutes (Harris et al., 2001). Therefore, there is good reason to question the implications that such an extended duration of parturition holds in terms of physiology, pathology, immunity, behaviour, welfare (extended time in pain), resilience, and performance of the pig. All of these essential aspects are profoundly affected by the present increase in litter size. A prevailing question is what could be done at the farm level in terms of management of parturition in order to alleviate the current problems. On the other hand, crossbreeding with less productive but more robust breeds may actually be a better alternative to improve the survival and immune state of newborn piglets and the health and welfare of the sow during the postpartum period.

An uncomplicated vaginal delivery of foetuses involves timely contractions of the uterine structures (Oscarsson et al., 2006; Berglund et al., 2008; Taverne and van den Weijden, 2008; Senger, 2012). While contractions are good in terms of the actual expulsion of the foetuses, they result in vasoconstriction of placental circulation, and ultimately rupture of the umbilical cord, exposing foetuses still within the uterus to oxidative stress. In the longer run, this leads to hypoxia (Oscarsson et al., 2006; Berglund et al., 2008; Taverne and van den Weijden, 2008; Boksa et al., 2015). If foetuses are subjected to hypoxia during the birth process, they are much more likely to be hypoglycaemic, less alert, and under increased risk of being crushed by the dam (Oliviero, 2013). This may indeed present a problem when very large litters are in the process of being born. Furthermore, these extra large litters also hold the risk of decreased piglet birth weight (Akdag et al., 2009; Beaulieu et al., 2010) and increased rate of intra-uterine growth retardation (IUGR) (Matheson et al., 2018; Oliviero et al., 2019). Such IUGR piglets are not only immature in terms of their immunity, but they are less active and need more time to achieve the first suckle. Furthermore, the ability of the sow to provide a reliable source of colostrum for all piglets may reach a limit, as the number of piglets approaches or even surpasses the number of functional teats (Spinka and Illmann, 2015). The window for access to colostrum is also shortened through prolonged farrowing in the hyper-prolific sows (Oliviero et al., 2019). Therefore, colostrum intake per piglet decreases with increasing litter size. An estimated 35% of sows do not produce enough colostrum to adequately supply all of their piglets (Quesnel et al., 2012). As a result, low birth weight piglets in large litters are at a greater risk of not obtaining at least 200-250 g of colostrum (Quesnel et al., 2012; Hasan et al., 2019), which is the amount needed for adequate immunoglobulin levels and minimum growth (Spinka and Illmann, 2015).

Another major problem that arises from extra large litters is an increased incidence of diseases of the udder and the uterus, resulting in decreased reproductive performance of the sow. Prior to parturition, hyper-prolific sows need to be fed according to the number of developing foetuses. This led to increases in the amounts of energy and feed provided to gestating sows. However, a greater volume of feed ingested in gestation is known to be a risk factor for the metabolism of periparturient sows, likely creating a negative energy balance (Feyera et al., 2018; Farmer et al., 2019). Increasing the volume of feed, and thus energy, is also a risk factor for constipation and poor mammary gland development (Farmer and Quesnel, 2009; Oliviero et al., 2010; Farmer and Hurley, 2015; Farmer et al., 2019), leading to insufficient colostrum and milk production and, therefore, low piglet survival and development (Edwards and Baxter, 2015).

After parturition, prolonged farrowing may be manifested as adverse development of microbiota in the sow (Hasan et al., 2018b). This may be due to the birth canal staying open for extended periods of time (Peltoniemi et al., 2019a). It is therefore not surprising that in hyperprolific sows a greater incidence of uterine problems and placental expulsion have been reported (Björkman et al., 2017a) as well as increased rate of uterine inflammation giving rise to postpartum dysgalactia (PDS, Björkman et al., 2018c). It was recently reported that the incidence of PDS has increased along with litter size, reaching the current value of 34% in the DanBred breed (Kaiser at el., 2018a;b). Therefore, the problems related to prolonged farrowing, which are highly associated with the hyperprolific sow (Oliviero et al., 2019), warrant careful consideration in future management and breeding. It is hypothesized that with optimal management the duration of farrowing may be decreased, improving the prospects for newborn piglets. However, cross breeding of the modern highly prolific sow lines back with the less productive but more robust breeds may be needed to cope with the evolving challenges. The following text will cover the management practices currently available for successful farrowing, reduction of duration of farrowing, optimization of colostrum production and intake by piglets, favourable changes in microbiota in piglets and sows, and a decrease in diseases such as PDS that affect the udder and the uterus.

Diagnosis of abnormal parturition

Behaviour during the first and second stages of parturition

The first stage of parturition overlaps with the time period of nest-building behaviour, which is a highly expressed, intrinsic behaviour of the pig occurring during the last 24 hours prior to the onset of the expulsion stage (Jensen, 1986; Algers and Uvnäs-Moberg, 2007). Nest-building activity is at its peak between 6 and 12 hours preceding the expulsion of the first piglet (for reviews, see Lawrence et al., 1997; Wischner et al., 2009). If space and materials for nest-building are lacking, sows may redirect the need for nest-building to other types of activities, giving rise to greater overall activity level during parturition. Thodberg et al. (2002) found that sows housed in pens without nesting materials expressed less nest-building behaviour and an increased frequency of attempts to express nest-building prior to the onset of expulsion of piglets. However, more nest-building like behaviour was observed in pens without nesting material during the expulsion (second) stage of parturition compared with pens provided with straw (Thodberg et al., 2002). Alternatively, inhibition of the expression of nest-building behaviour prior to the second stage of parturition by lack of space and substrates may provoke a stress response in sows. The stress response may then result in increased behavioural activities during parturition, thus delaying the farrowing process (for review, see Yun and Valros, 2015). The occurrence of prepartum nest-building behaviour was shown to be positively correlated with increased litter size (Pedersen et al., 2006). Therefore, providing optimal farrowing environment with adequate space and nesting materials appears particularly important for the hyper-prolific sow. It can encourage the performance of nest-building during the first stage of parturition. A supportive environment may therefore decrease stress and shorten the second stage of parturition.

After entering the second stage of parturition, postural changes decrease and duration of lying gradually increases (Figure 2). Harris and Gonyou (1998) proposed that frequent postural changes or restlessness can be indicative of the state of discomfort in peripartum gilts. Furthermore, our previous findings (Yun et al., 2019) suggested that suboptimal farrowing environments for sows with a large litter may cause considerable stress. The increased stress appears to induce a greater frequency of postural changes and longer duration of standing position of sows during the expulsion stage of parturition (Yun et al., 2019). Stress and discomfort of sows can therefore be suspected when there are no signs of cessation of activities such as nest–building in the beginning of the second stage of parturition.

Prolonged second and third stages of farrowing

Only a decade ago, a farrowing duration of more than five hours and a piglet birth interval longer than 25 minutes were considered excessively long farrowing (Oliviero, 2010). With the avenue of hyperprolific sows, the average farrowing duration has considerably increased. In fact, in Danish sows, the average duration of farrowing was recently reported to be 7 to 7,5 hours (Hales et al., 2015; Thorsen et al., 2017). Hence, it is important to recognize the signs of a prolonged farrowing both during the process and immediately after it. It is often recommended that the sow should be supervised and, if necessary, assisted during farrowing (Kirkden et al., 2013). Signs of prolonged farrowing could include restless behaviour, as discussed above, and strong abdominal straining due to acute obstructive dystocia (Cowart, 2007). On the other hand, weak or absent abdominal contractions in a calm sow most likely refer to uterine inertia. Dystocia in sows is relatively rare compared with other livestock species, but this condition has increased over the years from 0.5% to 5%, with an even higher incidence in modern hyperprolific sow lines (Jones, 1966; Randall, 1972; Peltoniemi et al., 2019a). In the past, when litter size was not so large, uterine inertia was considered mainly to be secondary due to fatigue of dystocia (Almond et al., 2006). On the other hand, large litters are nowadays the likely primary cause of uterine inertia due to a heavy and overstretched uterus and hormonal disturbances in the sow. Thus, prevention of prolonged parturition in hyperprolific sows is essential and will be discussed later in more detail.

If preventive measures fail to be successful, sows need more intense monitoring at farrowing. For instance, sows that are obese or show constipation during the days before expected farrowing should be monitored more carefully. Constipation and presence of excessive faecal material in the colon and rectum may result in partial occlusion of the birth canal (Cowart, 2007). One study reported an increase in farrowing duration associated with clinical constipation during the five days prior to farrowing (Oliviero et al., 2010). Another sign of prolonged farrowing is expulsion of the placenta during the second stage of birth. If the placenta is expelled before the last piglet, it is likely that parturition has been ongoing for more than five hours (Björkman et al., 2017a). On the other hand, expulsion of minor parts of the placenta or absence of placental expulsion after the last piglet is born may also be a sign of prolonged parturition. This may indicate a substantial slowing of the birth process (Björkman et al., 2017a). In summary, while litter size has doubled in the past three decades, duration of farrowing has increased by 4 to 5 times, hence presenting a great challenge for the pig industry.

Colostrum quality

Several studies report that 200 to 250 g of colostrum per piglet is the minimum requirement to induce sufficient immune protection (Devillers et al., 2007; Quesnel, 2011; Hasan et al., 2019). Colostrum production lasts only 16 to 24 hours after parturition starts, and already after the first 6 hours the IgG content in colostrum is halved (Le Dividich et al., 2005). However, by the sixth hour, there is still an average of 20% piglets still within the uterus in the hyper prolific sow (Oliviero et al., 2019) Those piglets miss out on access to colostrum of good quality. Therefore, especially when managing large litters, determination of the level of immunoglobulins in colostrum could be a useful tool. Hasan et al. (2016) proposed the use of the Brix refractometer to evaluate sow colostrum content of IgG on the farm. The IgG content in sows peaks shortly after the onset of farrowing, with reported concentrations 60 to 70 mg/mL at this time (Hurley, 2015; Quesnel, 2015). However, concentrations decrease to around 10 mg/ml at the end of colostrogenesis (24 h after the onset of farrowing). Colostrum should be tested with the Brix refractometer at the beginning of farrowing (0 to 3 h) when it is easiest to collect and when concentrations of IgG are expected to be near the peak values for this time period (Hasan et al., 2016). The authors considered an IgG content of 50 mg/mL as a fairly safe cut-off point to provide adequate amounts of IgG to newborn piglets. A table for evaluation of the Brix refractometer results is shown in Table 1. When Brix values are <20%, they reflect very low levels of IgG, while values from 25% upwards are considered to correspond to adequate or very good concentrations of IgG in colostrum. Values between 20% and 24% are defined as borderline, yet they should only be considered critical if within the lowest range of this category (20% to 21%). Therefore, with borderline results, the authors suggest taking another sample within 1 to 2 hours to determine whether the estimated IgG content is stable, increasing, or decreasing compared to the initial value. Using colostral Brix measurement at farm level may help to identify sows with impaired IgG concentrations in early parturition. In conclusion, the Brix refractometer could be used to increase stockmanship with large litters by routinely screening the colostrum quality of sows in the herd in order to detect unfavourable low levels of IgG as result of feeding, diseases, or management issues.

Ultrasonography and other biomarkers

A prolonged process of parturition is a high risk situation for impaired uterine health (Björkman et al. 2017a,c;2018a). Therefore, expertise in diagnostic imaging can be used peripartum to diagnose the causes of dystocia as well as postpartum to diagnose diseases of the reproductive tract. Whenever a sow shows signs of dystocia, an obstetric examination should be performed before any interventions are conducted. It is recommended to include ultrasound in the obstetric examination in order to visualize piglets located in the birth canal and other parts of the uterus. If a piglet is located in the birth canal, it is more likely that the cause of dystocia is an obstructive one. If there are piglets deep in the uterus and not in the birth canal, it is likely that the cause is a failure of expulsive forces. Ultrasound can also be used to see whether piglets are still present inside the uterus or whether the second stage of parturition is completed.

After parturition is completed, ultrasound is beneficial to determine uterine health. The timely and correct diagnosis of postpartum uterine disease is essential to prevent postpartum dysgalactia syndrome, hence, decreased neonatal development and survival as well as decreased subsequent fertility of the sow (Kauffold and Wehrend, 2014). Ultrasonography is considered to be the best tool for diagnosis of endometritis and retained placenta (Björkman et al., 2018c; Kauffold et al., 2019). Examination of uterine structures currently utilizes three criteria: fluid echogenicity, echotexture, and size (Kauffold and Althouse, 2007; Peltoniemi et al., 2016; Björkman 2017c). Increased size and echotexture are a reflection of oedema changes in the endometrium, which is usually abnormal. Nevertheless, the parity of the sow and the postpartum day on which the examination is performed need to be taken into consideration when interpreting uterine size. Furthermore, any fluid causing echogenicity must be considered abnormal and indicative of an exudative inflammation of an acute or acute-chronic type (Kauffold and Althouse, 2007). Fluid echogenicity is often associated with increased echotexture and size of uterine cross-sections (Björkman et al., 2018c), therefore sharing similar risk factors. These risk factors are prolonged parturition, obstetric intervention, placental retention, and birth of two or more stillborn piglets (Björkman et al., 2018c). Postpartum ultrasound can be used to diagnose retention of the placenta (Peltoniemi et al., 2016; Björkman et al., 2017a, 2017c; Kauffold et al., 2019).

Besides ultrasonography, other biomarkers have been extensively used to evaluate health status, establish a diagnosis or prognosis of the disease, predict and/or monitor response to therapy, and assess reproductive failure (Myers et al., 2017). Characteristics related to clinical signs such as vaginal discharge, total amount, colour, number of cells, and cell characteristics, are considered as biomarkers that are used to evaluate uterine health, but different variables are needed to strengthen a presumptive diagnosis of endometritis in sows after birth (Grahofer et al., 2019). As cystitis is one of the main risk factors for sows showing sustained uterine infections (Biksi et al., 2002), several useful biomarkers are described in the literature (Kauffold et al., 2010; Bellino et al., 2013; Grahofer et al., 2014; Sipos et al., 2014). Midstream urine samples are often contaminated through the environment, and therefore sterile urine or swabs from the bladder of culled sows should be tested and a culture performed if there are problems with the urinary tract in a sow herd (Grahofer et al., 2014; Sipos et al., 2014). Ultrasonography of the urinary bladder is inappropriate for the diagnosis of urinary tract infections in sows because the variables are dependent on filling of the urinary bladder. Only moderate to high amounts of sediment seem to be indicative of cystitis (Kauffold et al., 2010). Hence, a combination of several variables is necessary to diagnose infections of the urogenital tract in sows. In conclusion, ultrasonography with modern equipment appears to be a good tool to efficiently follow-up on the health status of the birth canal, uterus, and urinary tract in postpartum sows.

Treatment of abnormal parturition

Such new developments as the tendency towards free farrowing and the increased likelihood of heat stress with climate change require that researchers and the industry have a critical look at the breeding targets. It is likely that these new perspectives, e.g. free farrowing and thermal resilience, will need to be taken into consideration in creating new breeding goals (for review, see Peltoniemi et al., 2019b). Recent developments in reproductive technology should be helpful for international transfer of germ cells and embryos of more robust and resilient sow lines across borders that may be more suitable in free farrowing type of production and in areas where sows are suffering from heat stress (Hansen, 2019; Peltoniemi et al., 2019b). These developments include ovarian biopsy and ovum pick-up (Brüssow et al., 1997; Björkman et al., 2017d; Peltoniemi et al., 2019b), cryopreservation of germ cells and embryos (Cuello et al., 2016), and development of embryo transfer technology (Martinez et al., 2016).

Treatment of prolonged parturition

The role of biosecurity and expert level stockmanship are of highest value in obstetric interventions. Appropriate and prompt treatment of the sow during prolonged parturition is important to avoid negative effects on the sow's reproductive health and the piglets' health and survival. This can be achieved through continuous farrowing supervision (Holyoake et al., 1995). In general, obstetric intervention is indicated if more than 45 minutes have passed since the last piglet was expelled (Peltoniemi et al., 2019a). This especially applies if the sow is restless and has strong abdominal contractions or if parturition is prolonged beyond 300 minutes (Oliviero et al., 2008). If the sow is still at the beginning of parturition and shows no signs of discomfort or strong abdominal straining, obstetric intervention is usually not indicated before one hour has passed since the last piglet was born (Peltoniemi et al., 2019a). Most often maternal causes, such as secondary uterine inertia, lead to dystocia in sows. Nevertheless, general and obstetric examinations, including palpation and ultrasonography of the birth canal, are necessary to rule out other causes of dystocia, such as obstruction of the birth canal, ventral deviation of the uterine horns, or foetal malposition, before treating for uterine inertia (Peltoniemi et al., 2019a). Oxytocin provokes uterine contractions and it is frequently used during farrowing to treat dystocia (Straw et al., 2000). Use of oxytocin is only indicated when there is no obstruction of the birth canal, the piglet is well positioned, and the sow has poor uterine contractions (Gilbert,1999). Before administration of any exogenous oxytocin, it is recommended to try means of releasing endogenous oxytocin, e.g. manual induction of the Ferguson reflex through stimulation of the cervix or encouraging the sow to move, especially if the sow is still at the beginning of the second phase of parturition. Nevertheless, if secondary uterine inertia is diagnosed towards the end of the second phase of parturition, immediate injection of oxytocin is indicated (Peltoniemi et al., 2019a). Several studies were conducted to prove the effect of oxytocin on the birth process and piglet survivability and to evaluate the proper dosage of oxytocin in dystotic sows (Mota-Rojas et al., 2002; 2005a,b; 2007). An intramuscular administration of 10 IU of oxytocin did not cause any side effects. However, higher dosages (20 to 50 IU) led to an increase in stillborn piglets, changes in the umbilical cord, and greater meconium scoring (Mota-Rojas et al., 2002, 2005a,b, 2007; Kaeoket, 2006). Furthermore, improper use of oxytocin can increase uterine inertia (Dial et al. 1987). Hence, oxytocin should be only restrictively administered, e.g. a maximum of 10 IU one to two times during parturition. Recently, two studies investigated the use of carbetocin, a long-acting analogue of oxytocin, administered routinely after expulsion of the first piglet (Jiarpinitnun et al.,2019; Ward et al., 2019). Their findings indicated that while use of carbetocin may reduce duration of farrowing, it can also reduce colostrum yield and increase still born rate. Another study reported severe undesirable side effects after routine administration of 35 µg of carbetocin during the farrowing process in a free farrowing system (Grahofer et al.,2019). A prolonged piglet-to-piglet birth interval directly after application, loss of colostrum, and increased number of weak and stillborn piglets were also detected. Therefore, administration of carbetocin is not currently recommended to improve the birth process. In conclusion, timely application of birth assistance, considering behaviour of the sow and the time elapsed since start of parturition, has become more important than ever in hyperprolific sows. Hyper-stimulation of the uterus with excessive oxytocin must, however, be avoided. In addition, breeding goals of pig production should be re-examined for robustness and resilience.

Improving colostrum uptake

Once piglets are born, farmers need to quickly implement a strategy to reduce piglet mortality. This is important especially in large litters which have greater incidences of low-viability piglets and where competition for colostrum and milk access are increased (Lund et al., 2002; Devillers et al., 2011; Hasan et al., 2019). To provide all piglets with sufficient individual colostrum intake (200 to 250 g) within 12 to 16 hours from the beginning of parturition, different strategies can be adopted. When possible, small and low-viable piglets should be assisted to suckle, helping them to attach to the teat, and ensuring that they are able to ingest colostrum. Baxter et al. (2008) investigated behavioural and physiological indicators of neonatal survival and provided data that could be used to identify piglets in need of assistance (Table 2). Besides birth weight and crown-rump length, survival of piglets was positively related with rectal temperature between birth and 24 hours postpartum and with vitality score, rooting response, and latency to access a teat and suckle. These traits were also correlated with each other, showing the importance of prevention of the hypothermia-starvation-crushing complex in neonatal piglets, as summarized by Edwards and Baxter (2015). Those authors concluded that a piglet needs to be assisted to suckle if the following criteria are met: vitality of less than 2, meaning no movements within 15 seconds of birth, latency to access and suckle a teat of more than 30 minutes, and rectal temperature of less than 37°C during the first hour after birth. This may, however, be difficult to put into practice and it may be helpful to make use of thermal images to overcome these difficulties (Alexopoulos et al. 2018). As is the case with body temperature, skin temperature is linked to birth weight, vitality, and colostrum ingestion and can be used to determine whether a piglet has reached a teat, suckled, and ingested colostrum within 30 minutes of birth (Santiago et al., 2019; Zhang et al., 2019a). As a piglet begins to suck and ingest colostrum, energy and warmth are provided, increasing rectal and skin temperatures (Figure 3; Alexopoulos et al., 2018). If skin temperature drops below 30°C, the piglet has not been successful in suckling (Figure 3; Alexopoulos et al., 2018) and needs to be assisted to attach to the teat and ensure that it ingests colostrum. The digital measurements such as digital skin temperature in Figure 3 may be part of automated supervision of farrowing, which appears as an important and cost-effective part of future management of parturition. It is important to remember that small piglets have difficulties in suckling from teats with big nipples, and therefore, the smallest functioning nipples should be preferred when assisting suckling. This procedure should be repeated 3 to 4 times within the first few hours if these piglets are not seen to actively suckle at the udder. Additionally, low-viable piglets can be hand-fed with colostrum collected from their mother or other sows within 6 to 12 hours from the beginning of farrowing. Assisted suckling and hand feeding work well in small to normal litters with only one or two small piglets. In large litters and litters with more than two low-viable piglets, a split-suckling strategy could be more effective (Oliviero, 2013). To minimize sibling competition for colostrum intake, the litter is split into two groups. The more vigorous piglets with a full stomach are kept in the creep area or in a separate box, allowing the other piglets to suckle for 60 to 90 minutes, and then the groups are switched (Oliviero, 2013). This process is repeated as many times as possible. When separating the piglets, both groups should always have free access to a warm creep area. If some small piglets are still unable to successfully suckle, assisted suckling should be combined with split-suckling. In conclusion, litters from hyperprolific sows require close attention and assistance must be provided to late-born piglets, piglets without successful access to a teat, as well as underweight and less active piglets. New technology, such as the use of infrared cameras, may be utilized to assess the status of the newborn piglets.

Prevention

Feeding and mammary gland development

Adequate mammary gland development is important for optimal colostrum and milk production and this topic has been recently reviewed by Farmer and Hurley (2015). In terms of mammary gland development and ease of farrowing, ad-libitum feeding with low fibre high energy feed in the last third of gestation should be avoided and more attention should be directed to feed composition. Providing the right amount of crude fibre and an adequate uptake of crude protein and certain essential amino acids are important (Farmer and Hurley, 2015). Interestingly, restricted feeding (about 50%) during the last third of gestation seems to be beneficial since backfat loss in that period has been positively associated with colostrum yield (Decaluwe et al., 2013). Yet, this can only be recommended for sows in good body condition in order to achieve optimal body condition (Oliviero et al., 2010) and mammary development (Farmer et al., 2016) at parturition. These studies suggest that more than 16 mm of backfat should be achieved, while also avoiding over conditioning. However, one must ensure that gestating sows receive sufficient energy to satisfy the demands of the forthcoming lactation, hence, sows are usually fed with high-energy concentrated lactation diets during late gestation (Einarsson and Rojkittikhun, 1993). Such concentrated diets, which contain less fibre than standard pregnancy diets (at least 7% crude fibre), can promote obesity and constipation. These two conditions are associated with prolonged farrowings and an increased stillbirth rate (Oliviero et al., 2010). Late pregnancy diets should contain up to 7 to 10% crude fibre in order to reduce constipation and excessive fat depots (Oliviero et al., 2009). If the diet cannot be easily modified, a good fibre source can be provided by offering different types of roughage (straw, hay) or adding any other feedstuffs with high levels of fibre, such as sugar beet pulp (Quesnel et al., 2009). The provision of roughage may not only be a way of increasing fibre intake and alleviating constipation and obesity, but can also serve as an appropriate material for nest - building. Proper nest-building behaviour is linked to lower concentrations of progesterone and greater concentrations of prolactin prepartum (Algers and Uvnäs-Moberg 2007). A high prepartum prolactin to progesterone ratio is also needed for adequate colostrum production (Foisnet et al., 2010). In addition, the use of dietary fibre can promote a better colostrum yield (Foisnet et al., 2010). Feeding fibre to gestating sows can also influence their gut microbiota, increasing the number of bacteria that are able to breakdown and ferment complex carbohydrates into short-chain fatty acids (SCFAs, Jha et al., 2019). The SCFAs produced by bacteria are thought to provide up to 30% of the maintenance energy requirement of gestating sows (Varel and Yen, 1997). Moreover, an increase in the concentration of SCFAs, more specifically butyrate, can improve gut mucosal health and the immune system of pigs. A recent study reported that an increased amount of cellulolytic bacteria such as *Paraprevotella and Roseburia* in the gut of sows was correlated with greater colostrum production (Hasan et al., 2018a). Moreover, the mother can influence the gut microbiota of her piglets, which was shown to improve piglet growth performance (Hasan et al., 2018a; Cheng et al., 2018). Another avenue that was recently investigated is the sow glucose metabolism shortly before and during the expulsion stage of farrowing. More specifically, Feyera et al. (2018) found that a short time lapse (less than 3 hours) between the last meal and the onset of the expulsion stage shortened the duration of farrowing. Therefore, it appears that modifying the sow's late gestation diet as well as providing the sow with frequent access to feed prior to farrowing can have beneficial effects on colostrum production and health of the sow, and on piglet growth.

In addition to improving mammary gland development for optimal colostrum and milk production, health of the mammary gland should be assessed before and after parturition. Before parturition, it is important to assess the number and morphology of functional teats and the degree of oedema. After parturition, it is important to assess the mammary gland for any injuries or inflammation. The number of functional teats available per piglet is positively associated with piglet survival. If piglets have access to less than one functional teat, mortality increases by more than 14%. However, if more than one teat is available, mortality may be reduced to below 8% (Vasdal and Andersen, 2012; Alexopoulos et al., 2018) instead of the commonly reported mortality of 16 to 20 % (Edwards and Baxter, 2015). Besides the number of functional teats, morphology of the udder is important. Piglets tend to suckle first from teats that are close to the abdominal midline and have longer inter-teat distances (Alexopoulos et al., 2018). Thus, a functional teat with short inter-teat distance and/or long distance between teat base and abdominal midline may be unusable for the piglet (Balzani et al., 2016). Furthermore, severe oedema of the mammary gland before parturition will have a negative impact on teat accessibility, reduce colostrum quality, and increase the risk of subsequent mastitis (Björkman et al., 2017b and 2018a). The degree of mammary gland oedema can be graded visually or with the aid of ultrasound, and a tissue sample by biopsy is also possible (Björkman et al., 2017b; 2018a, 2018b; Han et al., 2018). It is important to keep in mind that the number of teats and teat morphology are factors that should be considered in farrowing management.

The immune system and microbiota

With regard to colostrum quality, there is a strong relationship between the process of parturition and maternal or piglet immunity. When the process of parturition is prolonged, the endocrine and immune systems are disturbed. Maternal nutrition plays a vital role in foetal development, early development of neonates, and lactation performance, and it regulates the lifetime productivity of the offspring (Zhang et al., 2019b). Nutritional strategies include feed additives such as organic acids, short- and medium-chain fatty acids, probiotics, prebiotics, and certain specific carbohydrates. After parturition, maternal nutrition can also affect development of the immune system in piglets (Salmon et al., 2009). Many studies have reported that supplementation with specific essential fatty acids (conjugated linolenic, linolenic and oleic acids, and resin acid-enriched composition) in gestating and lactating diets can improve colostral immunoglobulin concentrations, average daily gain, and weaning weight (Bontempo et al., 2004; Corino et al., 2009; Yao et al., 2012; Hasan et al., 2018b). The exact mechanisms underlying how these dietary components can increase different colostral immunoglobulins are not yet fully understood. However, their use in specific conditions of large litters and reduced colostrum quality could be beneficial (Oliviero et al., 2019). A recent study investigating late pregnancy diet supplementation with resin acid-enriched composition (RAC) reported that sows fed this compound had a relatively lower abundance of *Proteobacteria* in the hind gut (Hasan et al., 2018b). This can be considered beneficial for the sow because a high prevalence of *Proteobacteria,* representative of an unstable microbial community (dysbiosis), is a potential diagnostic criterion for diseases in humans (Shin et al., 2015). *Proteobacteria* are also linked to intestinal inflammation (Mukhopadhya et al., 2012). Bacteria belonging to the

Proteobacteria phylum are known to cause intestinal diseases in humans and animals (Salyers and Whitt, 2002) indicating that RAC might contribute to the balance of intestinal microbiota. Sows fed RAC had more stabilized gut microbiota and reduced risk of pathogen colonization. *Barnesiella, Sporobacter, Intestinimonas,* and *Campylobacter* decreased in the hindgut of the RAC group, while *Romboutsia* and *Clostridium sensu stricto* significantly increased. *Barnesiella, Sporobacter, Intestinimonas,* and *Campylobacter* are well-known initiators of inflammatory diseases and gastrointestinal disorders in humans and animals (Weijtens et al., 1999; Zhang et al., 2017). On the other hand, *Romboutsia* and *Clostridium sensu stricto,* the main energy source for colonocytes, produce SCFAs by anaerobic fermentation of dietary components and protect from inflammation (Lopetuso et al., 2013). *Clostridium sensu stricto* is reported to promote the intestinal mucus barrier, and thus to inhibit adherence of pathogenic microbes (Wlodarska et al., 2015). In another study, supplementation with a hydrolysate yeast derivative (YD) in the late gestation diet increased colostrum yield and microbiota in sows (Hasan et al., 2018a). More beneficial and fermentative bacteria (*Roseburia*, *Paraprevotella*, *Eubacterium*) were found in the YD-fed group, while some opportunistic pathogens, including *Proteobacteria*, especially the genera *Desulfovibrio, Escherichia/Shigella,* and *Helicobacter*, were suppressed. At one week of age, piglets born from YD-fed sows had better microbial populations with significant diversity and fewer opportunistic pathogens (Hasan et al., 2018a). Interestingly, the increased abundance of families of *Proteobacteria* (*Enterobacteriaceae*, *Desulfovibrionaceae, Desulfovibrionaceae*) in the control group was associated with low colostrum yield, low colostrum proteins, low colostrum IgM and high stillbirth rate (Hasan et al., 2018a). In conclusion, targeted feeding strategies could favourably modulate colostrum production, colostrum immunoglobulin content, and gut microbiota of sows, hence indirectly benefiting piglets.

Conclusions

This review outlined current management and nutritional strategies arising from the large increase in sow litter size. Breeding goals should be reconsidered, addressing the ever-increasing duration of parturition in this species, which is not sustainable. In addition, attention should be paid to improving the international trade of germ cells and embryos in order to better cope with the challenges of the large litter. Other challenges await, including free farrowing housing and better resilience of sows as they approach farrowing to allow them to cope with the potential heat stress brought about by climate change. Behavioural traits can be useful for diagnosis of abnormal parturition. Sows should be allowed to express nest-building behaviour and deviations from normal behaviour just before and during the expulsion phase of parturition may indicate problematic cases. In addition, ultrasound technology is very useful, especially during the last third of pregnancy and postpartum, so that the most appropriate actions can be taken with regard to uterine health. Proper feeding management during the last third of pregnancy is crucial for mammary development and appropriate colostrum production. Prevention of constipation through adequate fibre provision and frequent meals prior to the onset of farrowing are important in the hyperprolific sow. Feeding management can be used to promote the immunity of the sow and the newborn. Feeding components, such short-chain fatty acids and yeast derivate, also appears to promote a favourable microbiota of the sow. Neonatal care and management become critical with large litters. The focus should be on situations where the number of piglets is greater than the number of teats. Applications of new technology, e.g. infrared cameras, may be useful in detecting piglets in need of assistance. In addition, such practices as cross fostering and split suckling are necessary when trying to handle the increasing litter size. The on-farm use of a Brix refractometer permits estimation of the quality of colostrum at the individual sow level, thereby allowing the farmer to target actions at specific sows that produce low-quality colostrum.

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Table 1. Colostrum IgG content based on two methods of evaluation and the categories of estimation.

Brix %	ELISA IgG 0-3 h, mg/ml, average ± SEM	IgG estimation categories
< 20	14.5 ± 1.8	Poor
20-24	43.8 ± 2.3	Borderline
25-29	50.7 ± 2.1	Adequate
≥ 30	78.6 ± 8.4	Very good

From Hasan et al. (2016) Animal

Table 2. Significant postnatal survival indicators (means and standard errors (S.E.)) comparing surviving piglets with those dying during the neonatal period (adapted from Baxter et al., 2008).

Traits	Surviving (±S.E.)	Dying (±S.E.)	P-value
Piglet traits			
Crown-rump length (cm)	28 (± 0.26)	25 (± 0.90)	<0.001
Birth weight (g)	1485 (±30.25)	1176 (±79.35)	<0.001
24 h weight (g)	1584 (±34.1)	1035 (±70.2)	<0.001
Birth temperature (°C)	37.70 (±0.13)	36.47 (±0.61)	0.012
1 h temperature (°C)	37.94 (±0.10)	36.70 (±0.48)	0.002
2 h temperature (°C)	38.02 (±0.07)	37.54 (±0.33)	0.047
3 h temperature (°C)	38.02 (±0.06)	37.53 (±0.13)	0.010
24 h temperature (°C)	38.29 (±0.07)	37.58 (±0.26)	0.004
Piglet behavioural traits			
Vitality score	2.28 (±0.06)	1.77 (±0.20)	0.017
Rooting response (m)	1.42 (±0.10)	0.47 (±0.17)	<0.001
Latency to teat (min)	22 (±1.24)	34 (±6.52)	0.025
Latency to suckle (min)	29 (±1.67)	53 (±8.32)	<0.001

Figure 1. Relationship between litter size and duration of farrowing in 20 studies from 1992 to 2018 (Oliviero et al., 2019).

Figure 2. Mean duration of standing or locomotion, sitting, and sternal and lateral lying-down postures and mean number of postural changes per hour in 31 sows during the 2 h prior to onset of expulsion stage of parturition (a) and during the expulsion stage of parturition (b) for sows housed in closed or open farrowing crates (modified from Yun et al., 2019).

Figure 3. Thermal image detecting skin temperature of newborn piglets receiving colostrum (right: 36.2°C) or failing to reach the udder and ingest colostrum (left: 22.0°C). Image taken by Jena G. Alexopoulos (Alexopoulos et al., 2018).