

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

185,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Troubled Process of Parturition of the Domestic Pig

Claudio Oliviero and Olli Peltoniemi

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 group housing of sows during gestation, farrowing and lactation, focusing on management strategies of the sow. In short, the sow needs to be given space and enrichment materials for adequate expression of nest-building behavior. Maternal characteristics may be utilized to improve the success rate of reproductive management during farrowing and early lactation. 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.

Keywords: hyper prolific sow, large litters, group housing, parturition process, feeding management, colostrum management, gut microbiota

1. Introduction

In the pig, just as in other mammalian species, the process of parturition includes three phase: opening of the cervix (I), expulsion of the fetuses (II) and expulsion of the placentae (III). In the 1990's, the average duration of farrowing was 1.5–2 hours [1]. Since 1990, there has been a linear increase in both 1) litter size from about 10 piglets in 1990 to close to 20 piglets in 2019 and 2) duration of farrowing from 1.5–2 hours to 7–8 hours (a conclusion based on 20 studies on duration of farrowing, **Figure 1**, [2]). While the described tendency is subject to differences between breeds and management (i.e. farrowing crate vs. free farrowing), the overall tendency is rather convincing. The extended duration of farrowing appears an outcome of intensive breeding for prolificacy in the pig [2].

The increasing litter size presents with an immunological challenge for the sow and especially the piglets [2, 3]. The last 20–30% of the fetuses to be born likely miss out on access to good quality colostrum that declines by 50% already by the 6th hour after the birth of the first piglet [4]. On the other hand, they also have less time to suckle colostrum due to decreased window of opportunity for colostrum intake,

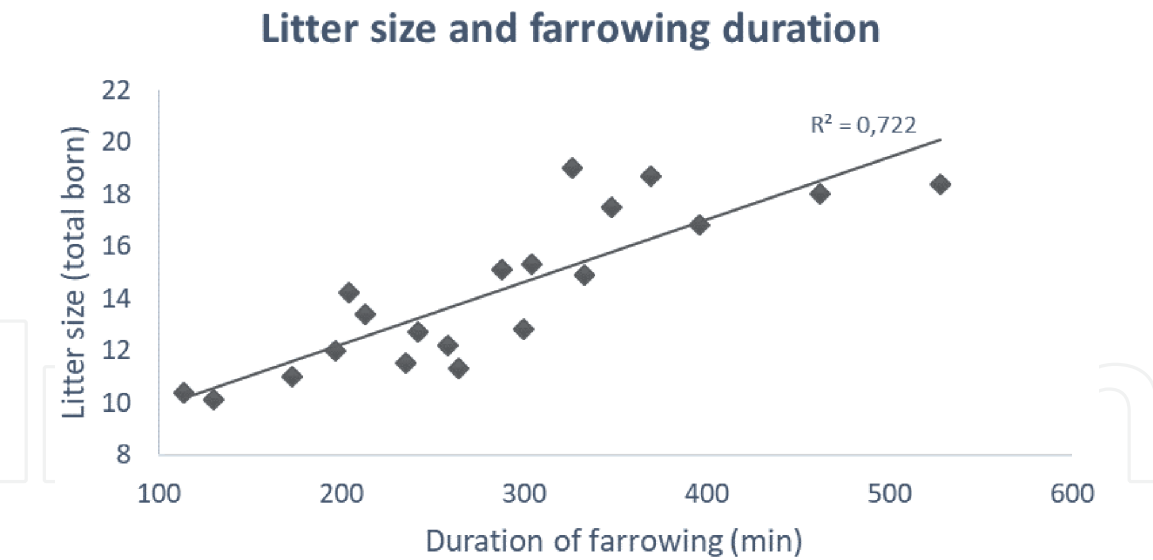


Figure 1.
Relationship between litter size and the duration of farrowing in 20 studies from 1992 to 2018 (adapted from Oliviero et al. 2019, reproduction in domestic animals, Wiley-Blackwell).

increased competition for teats and reduced birth weight. This all may show up later in emergence of diseases in the growing phase of piglets/fattening pigs.

The metabolic challenge related to hyper-prolific sow production model begins in the growing phase of gilts and goes beyond farrowing and lactation. The sow is supposed to eat enough to meet the requirement of growing litters prior to farrowing, which may cause some of the problems seen at around farrowing [5, 6]. In the early part of lactation, sows with large litters loose more energy while producing milk than what they can consume in their feed, ending up in a negative energy balance (NEB) [7, 8].

The growing litter size and intensity of production as such appear as items for welfare concern for the public. This seems to happen regardless of whether those concerns would be warranted or not. However, this review will tackle those items relating to welfare of the hyper-prolific sow model that we know, based on scientific literature, as having reasons to be addressed.

2. Physiology of parturition: low state systemic inflammation involved (PDS)

Nest building and the phases of farrowing are orchestrated by responding changes in reproductive hormones. It is well established that decline in progesterone and peak in prostaglandin F2alpha triggers nest building behavior while oxytocin rise at the beginning of expulsion phase marks the session of nest building [9]. Prostaglandin F2alpha peak also induces CL regression with a concomitant decline in progesterone, making uterine contractions and parturition possible. Oxytocin is mainly in charge of uterine contractions during the expulsion phase of parturition and letdown of colostrum and milk, while prolactin will promote mammary gland development to the extent that initiation of milk production after parturition will become possible [10–12].

It has also been described in the literature and also shown by our group that allowing the sow to build up a nest prior to farrowing will increase oxytocin release and shorten the duration of farrowing [5, 13]. Other ways of shortening the duration of farrowing include increasing fiber in the feedstuff and encouraging water intake [5, 14]. However, even applying most good management interventions prior

to farrowing, duration of farrowing of modern hyperprolific sows is extended four – to five fold as described [2, 15, 16]. Prolonged duration of farrowing will mean reduced quality and quantity of colostrum intake by piglets, increased degree of intrapartum hypoxia of fetuses [17], increased rate of retained placentae [18], increased rate of uterine inflammation and post partum dysgalactia (PDS) [19] and likely, reduced development of next generation of follicles fertility [3, 17].

Moreover, during the periparturient period, biological mechanisms coordinate the mobilization of body reserves in order to support fetal growth and milk production; insulin concentrations are reduced and the response of hormone-sensitive lipase in adipose tissue (e.g., low insulin, high growth hormone and catecholamines, or high glucocorticoid concentrations) is greater to facilitate lipid mobilization. This periparturient period is also characterized by a low state of inflammation encompassing an increase in hepatic production of positive acute-phase proteins (APP), and a decrease in the production of negative APP [15, 20]. It has been rather well described in the literature that these responses are mediated by the pro-inflammatory cytokines interleukin (IL)-6, IL-1 β , and tumor necrosis factor- α (TNF- α) [15]. Additionally, evidence in the dairy cow indicates that oxidative stress also occurs during this period and is driven by the imbalance between the production of reactive oxygen metabolites (ROM), reactive nitrogen species (RNS), and the neutralizing capacity of antioxidant mechanisms in tissues and blood [21]. The extent and duration of the inflammatory process will determine whether or not the condition is ending up as a clinical disease. However, it is noteworthy, that in the hyper prolific sows lines as those typical of Denmark and Belgium, the incidence of sows contracting a systemic disease postpartum is as high as >30% [15, 22, 23]. Moreover, it is obvious that even in those sows staying healthy as far as clinical symptoms, the inflammatory process is heavily present as indicated by means of those markers described above [15].

Typically, within two to three days post partum, the process of inflammation may develop into endotoxemia, which involves the release of the inflammation markers described. Endotoxemia is associated with clinical symptoms indicating a systemic response to infectious agents such as coliform bacteria – and PDS [24–26]. The condition comes with acute general symptoms such as inappetite, lethargy and fever [25], followed by local symptoms that usually affect either the uterus [19] or the udder [27] or both of them.

After parturition, concomitant with the process of inflammation, the sow undergoes metabolic stress due to loss of body reserves in favor of milk produced for large litters. This change rate is highest during the first 10 days of lactation. One of major mediators of metabolic stress is IGF-1, which is also seen as an indicator for fertility. Low IGF-1 levels indicate inflammation, metabolic stress present and fertility. IGF-1 is also regarded as one of the most important factors driving follicle development [28–30]. The role of extracellular vesicles, although proposed as being key players in follicle development and the cross talk between the mother and the embryo, in this inflammatory process and its effect on follicle development, however, remains less explored [31].

In conclusion, in hyperprolific sows, the physiological process of farrowing is prolonged, making the system vulnerable in terms of increased rate of inflammation and emerging infectious uterine and mammary disease. In fact, recent evidence now shows that even in sows staying without symptoms, there seems to be considerable degree of “silent inflammation” in the body. In an increased proportion of sows, however, post partum disease PDS is detected and hopefully treated. The consequences of inflammation, regardless of clinical symptoms, include reduced quantity and quality of piglet colostrum intake and milk intake during early lactation.

3. Challenges with transfer of immunity to piglets

The neonate piglets are born without the protection of immunoglobulins because of the epitheliochorial nature of the porcine placenta, which does not allow transfer of large molecules during the maternal-fetal interface. Neonate piglets must acquire maternal immunoglobulins from ingested colostrum for passive immune protection, before they will adequately produce own immunoglobulins at 3–4 weeks of age [32].

In Europe in the last 30 years there has been a constant increase in number of piglets born, with litter size averagely increasing from 11 to 14 piglets, with some countries reaching an average of 16 piglets [33, 34]. Nowadays, having litters up to 18–20 piglets it is not uncommon when raising hyper-prolific sow lines [18, 34, 35]. Because sows can have averagely an udder with 14–16 teats [36], large litters are challenging to manage during lactation. According to Andersen et al. [37], without balancing of litter size after birth and without any direct help to sow and piglets, a sow is able to wean successfully no more than 10 to 11 piglets. Large litters can also directly affect piglets at birth. The larger is the number of piglets born in a litter, the lower is their average birthweight and the higher is their weight variation within the litter [38–41]. A greater number of piglets born than the available teats at the sow's udder, a lower birthweight and a greater birthweight variation, all increase the piglets' competition for colostrum intake [42]. Similarly, lower birthweight and long farrowing duration are associated with lower piglet vitality at birth, which can delay the access to the udder [43, 44].

The constant presence of maternally secretory IgA (sIgA) in milk guarantees the protection of the intestinal mucosa of piglets. As long as piglets are able to intake sufficient amounts of milk, the sIgA give a localized protection to their intestine, allowing them to develop gradually their own immune response mechanisms [45]. Other immunoglobulins, like IgG are more concentrated into colostrum, with most of colostrum produced before farrowing and right after farrowing [46]. Porcine colostrum contains very high levels of IgG (30–70 g/l) and a mixture of bioactive molecules like growth factors and enzymes. In colostrum, the level of IgG may be four times higher than the level of IgA and IgG in the serum of the sow [2]. Closure of the gut junctions in piglets occurs 24–36 h after their birth, making the absorption of immunoglobulins impossible [32]. Impossibility for piglets to obtain timely a sufficient intake of colostrum is considered the main cause of piglet deaths occurring within the first days after birth [47]. The recommended amount of colostrum needed per piglet is at least 200 g to minimize the mortality and 250 g for good body weight gain [47]. Since the amount of colostrum offered is timely limited by the sow own production, there is a possibility that in large litters some of the piglets may suffer lack of colostrum. Lessard et al. [48] suggested that the genes' expression of immunity and oxidative stress in piglets' intestinal tissue can be affected by birth weight and colostrum intake, with direct effects on the leukocyte populations responsible of innate and cell-mediated immunity of nursing piglets. Piglets born with low weight had a lower amount of intestinal antigen presenting cells and an impaired increase of B cells, when compared to high birth weight piglets [48].

Social stress conditions like competition for colostrum and milk intake, crowding, and regrouping are more common in large litters. These conditions may induce short- and long-term effects in pigs, on their immunity. Psychosocial stress may alterate changes in the reactions of both the innate and adaptive immunity, such as leukocyte distribution, cytokine secretion, lymphocyte proliferation, antibody production and immune responses to viral infection or vaccination [49]. In addition, social stress may induce or promote gastrointestinal (GI) diseases through dysregulation of inflammatory processes and glucocorticoid resistance of lymphocytes [49], cortisol being the main stress-induced glucocorticoid in pigs.

Some studies found an increased association between high pre-weaning mortality and large litters [50, 51], one example is given in **Figure 2** for the Netherlands. An explanation to this correlation can be found in prolonged farrowing duration and lower birth weight commonly seen in large litter size [2].

In a recent study performed in Norway they found that, on the first day of life, the level of piglet plasma IgG, was affected negatively by a linear decrease of 0.4 g/L for each piglet born, indicating how prolonged parturition in large litters can impair the uptake of passive immunity of neonate piglets [52]. Several studies report a negative correlation between litter size and piglet birth weight [38–40, 53]. When looking to piglets' individual growth, three different studies consistently found a decline in litter average birth weight, ranging from 35 to 43 g for each additional pig born across three different populations of litters recorded [39, 40, 54]. A lower birth weight can affect negatively colostrum intake, increasing the risk of mortality [55–57]. Piglets serum IgG concentrations increased with increased piglet weight, while piglets from larger litters had lower serum IgG [58]. Similarly, greater amount of colostrum ingested at birth increased the IgG content in serum of piglets at 24 h after birth [59]. Another study found that piglet serum IgG concentration at 24 h, 10 and 20 days of age was positively correlated with colostrum intake and with the serum IgG concentration of the mother, but was not correlated with birth weight [56]. Increased duration of farrowing in combination with larger competition in the litter, can reduce not only the possibility to intake adequate amount of colostrum, but also retard the time of access to the udder. This is an unfavorable condition considering that colostrum level of immunoglobulins declines fast after the start of parturition [57]. Studies report that a delayed intake, after the birth, of a standard colostrum ration affected negatively the piglets' immunoglobulin absorption and the maturation of their intestinal villi, having possibly long-term harm on their digestion process [60]. A retarded detection of IgG in piglets' serum was reported when the standardized colostrum portion was given only after 12 h from their birth, than in piglets getting it immediately after the birth. The latter piglets had 4.4%

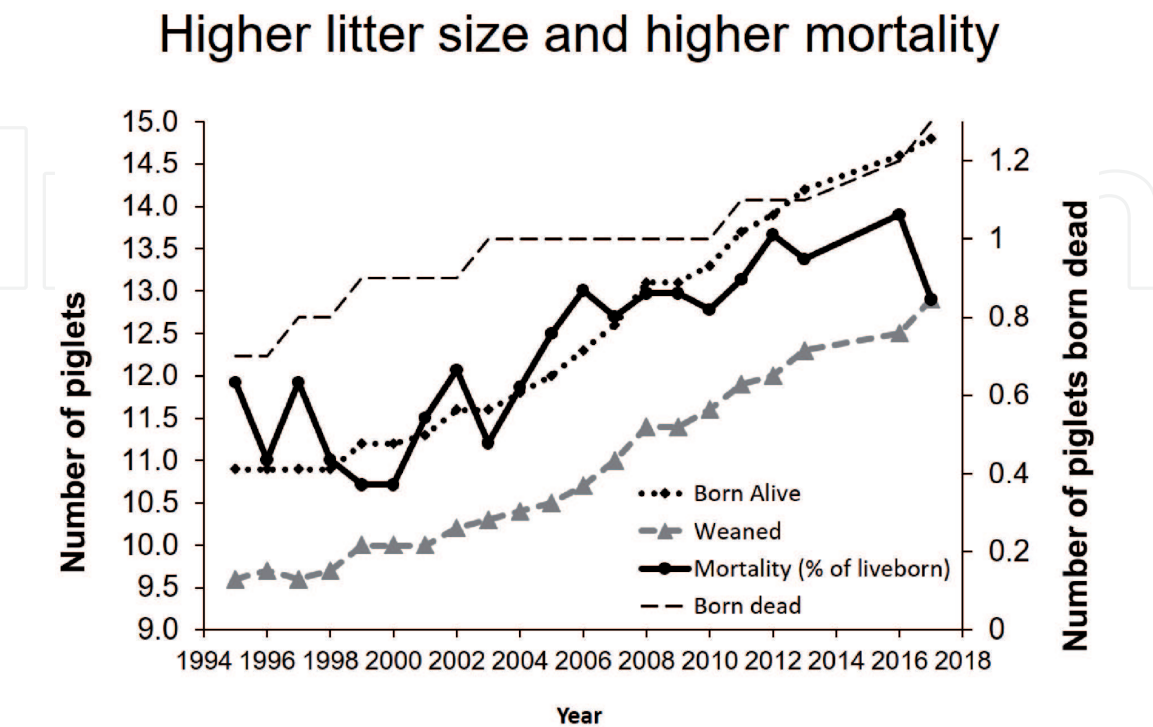


Figure 2.
Increased mortality with increased litter size in the Netherlands (adapted from: AgroVision B.V. the Netherlands, 2017).

more plasma IgG (21.5 vs. 17.1%), probably because of their greater development of intestinal villi [60]. Klobasa et al. [61] found that birth order had an influence on the amount of immunoglobulin absorbed in a population of 600 piglets. The latest piglets born in the litters had the lower IgG level in their plasma, due to the fast decline in colostrum immunoglobulins level from the start of parturition. Correspondingly, another study reported a 4% decrease of plasma IgG concentration in piglets of smaller birth weight, when compared to their bigger siblings [62]. Manjarin et al. [63] indicated the farrowing-to-suckling interval to be fundamental in the acquisition of adequate IgG by piglets. A 4 h delayed intake of colostrum, after the start of parturition, significantly reduced the amount of piglets' plasma proteins 24 hours up to 12 days. It is therefore extremely important to consider also the time of birth of piglets in relation to the start of farrowing, when planning successful strategies to boost colostrum intake in large litters, like for instance split suckling [2].

4. Microbiota involvement during pregnancy, parturition and lactation

The composition of gut microbiota constantly shifts over time and it is not constant. In sows, both diversity and abundance of certain microbial population increase with progression of the pregnancy until weaning [64]. Diversified gut microbiota can provide different metabolic capacities and functionality in sows, ensuring the sufficient supply of nutrients for fetal growth and development [64]. In a recent study carried out by Hasan et al. [65], at farrowing, from a phyla level perspective, most gut bacteria were classified in Firmicutes, Bacteroidetes, Proteobacteria, Actinobacteria, and Candidatus. The Firmicutes represent the most abundant proportion of the total population, followed by Bacteroides. These two phyla accounted for approximately 98% of all bacteria present. These results are in line with the one published by Kim et al. [66], reporting Firmicutes and Bacteroides being 90% of total bacteria present in late pregnancy in the sow gut. However, the findings of the study by Ji et al. [64], reported that Bacteroides increased linearly with the progression of the pregnancy and represented the most dominant (45%) in late pregnancy. Jost et al. [67] reported that Firmicutes exhibited no detectable changes over perinatal period. There are some evidences that gestational body weight gain or increase in the back-fat thickness in the sows, may be associated with an increase in the abundance of Firmicutes or an increase in the Firmicutes to Bacteroides ratio [64, 68]. In terms of phyla, the abundance of Tenericutes, Fibrobacteres, and Cyanobacteria have been shown to increase with the progression of the pregnancy [64]. These phyla have some beneficial effects, for example, Tenericutes increase intestinal cells' integrity and Fibrobacteres are characterized by having the potential to metabolize non-soluble polysaccharides, such as cellulose, hemicellulose or pectin [64]. During late gestation *Romboutsia* was the dominant genus in sows which is from the phylum Firmicutes, followed by *Clostridium sensu stricto*, *Lactobacillus*, *Oscillibacter*, *Intestinimonas*, *Sporobacter*, *Christensenella*, *Barnesiella*, *Flavonifractor*, *Terrisporobacter*, *Acidaminobacter*, *Lachnospiracea incertae sedis*, and *Turicibacter*, other genera being much less 1% [65].

The changes in the diet can differentiate the composition of the microbiome, and in its potential functionality. Recent studies demonstrate the importance of dietary microbial modulation. Dietary supplementation of hydrolysed yeast [65], resin acid enriched composition [69], probiotics [70] and prebiotics [71, 72] in sow's late gestation diet, significantly changes microbial populations. Different levels and types of protein and fiber in the diet are also modulating the gut microbial population both in gestating sows and in weaning piglets. Fiber has various

physicochemical properties, and its supplementation during pregnancy effectively enhances the stability of the gut microbiota population in sow [71, 72]. The most important changes in the gut microbiota composition include a reduction in Proteobacteria and an increase in Ruminococcaceae, Oscillospira, and Eubacterium. Additionally, the genus Eubacterium increases, after dietary soluble fiber supplementation during pregnancy, promoting propionate release, being one of the possible reasons by which dietary fiber increases insulin sensitivity and decrease the general inflammation in sows around farrowing [73]. Those microbiota capable to ferment indigestible carbohydrates, produce short chain fatty acids (SCFA) that can be an important energy source for the sow. Butyrate, in particular, is a gut health-promoting compound that acts as the main energy source for colonocytes and exerts anti-inflammatory properties [74]. The increased production of SCFAs promotes intestinal energy availability, which may contribute to the high energetic demands of hyper-prolific sows for the longer duration of farrowing process; therefore promoting the presence of fiber degrading gut microbiota seems to be favorable for gestating sows. The reduction of pathogenic bacteria in response to dietary supplementation is associated with an increase of beneficial microbiota, which in turn may modify the substrate availability and the physiological conditions of the gastrointestinal tract (e.g. fermentation products, luminal pH and bile acid concentration) [75]. Dietary supplementation of yeast hydrolysate in the pregnancy influenced beneficial and fermentative bacteria (Roseburia, Paraprevotella, Eubacterium), while, some opportunistic pathogens like Desulfovibrio, Escherichia/Shigella and Helicobacter, of the phylum Proteobacteria, were suppressed [65].

Proteobacteria are usually a minority presence within a normal gut microbial community [76]. However, a dysbiotic expansion of facultative anaerobic Proteobacteria are connected with gut inflammation, including irritable bowel syndrome, inflammatory bowel disease in humans [77], and with increased inflammatory responses of women in late pregnancy [78]. Recent studies have proposed that an expansion of Proteobacteria in the gut microbiota community is a potential diagnostic criterion for dysbiosis in gut microbiota and epithelial dysfunction [79, 80]. For instance, Hasan et al. [65] found that some positive sow's productive and physiological performances (high colostrum yield, high colostrum proteins content, high colostrum IgG content, normal blood progesterone level and normal farrowing duration) were positively correlated to the gut bacterial families *Lactobacillaceae*, *Ruminococcaceae* and *Prevotellaceae*, the last two being bacteria able to utilize different plant cell wall polysaccharides. On the contrary, unfavorable productive and physiological performances of the sow (low colostrum yield, low colostrum proteins content, low colostrum IgG content, high level of blood progesterone and long farrowing duration) clustered and were positively correlated with the gut bacterial families *Erysipelotrichaceae*, *Clostridiaceae*, *Streptococcaceae*, *Enterobacteriaceae*, *Desulfovibrionaceae* and *Bacteroidaceae*, many of these being known pig pathogens bacteria or part of the dysbiotic phylum Proteobacteria.

5. Robustness needed, resilience favored

The climate change requires a brave vision regarding breeding goals in the pig in the future. Buildings housing pigs will need to be energy saving and reducing CO₂ emissions in the future. On the other hand, hotter climate will need pigs to be robust and more resilient under heat with less susceptible to becoming stressed under those conditions. Hyper-prolific sows, however, may actually be quite sensitive to heat in comparison to less productive breeds [81].

Consumers appear to asking for improved welfare such as provided by free farrowing /free lactation discussed earlier [34]. Therefore, there appears to be growing demand for cross breeding/genes for these characteristics and traits. Recent developments in reproductive technology may provide tools for international trade of germ cells and embryos in the near future.

6. Conclusions

The process of parturition is long and complicated in the hyperprolific sow. It brings about increased risk of uterine contamination, mammary gland inflammation and retained placenta, therefore increasing post partum inflammation leading up to post partum dysgalactia PDS. From the fetal/neonatal point of view, hypoxia may develop due to the extended expulsion phase of parturition. Moreover, the quality and quantity of colostrum intake goes down when the decreasing window for suckling. In the early lactation, metabolic stress is profound due to the increased demand for energy and nutrients, which worsens the negative energy balance and may affect development of next generation follicle development and thereby future generations of piglets. Environmental and dietary effects on the gut microbiota of sows and piglets have an impact during gestation, farrowing and lactation, possibly improving performances of hyperprolific sows and of piglets in large litters.

Author details

Claudio Oliviero* and Olli Peltoniemi
Department of Production Animal Medicine, Faculty of Veterinary Medicine,
University of Helsinki, Saarentaus, Finland

*Address all correspondence to: claudio.oliviero@helsinki.fi

IntechOpen

© 2020 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

References

- [1] Jackson PGG. Handbook of Veterinary Obstetrics. 2nd ed. London: Saunders; 1995. p. 221-222
- [2] Oliviero C, Junnikkala S, Peltoniemi O. The challenge of large litters on the immune system of the sow and the piglets. *Reprod Dom Anim*. 2019;54(Suppl. 3):12-21. DOI: <https://doi.org/10.1111/rda.13463>
- [3] Oliviero C, Kothe S, Heinonen M, Valros A, Peltoniemi O. Prolonged duration of farrowing is associated with subsequent decreased fertility in sows. *Theriogenology*. 2013;79:1095-1099
- [4] Le Dividich J, Charneca R, Thomas F. Relationship between birth order, birth weight, colostrum intake, acquisition of passive immunity and pre-weaning mortality of piglets. *Spanish Journal of Agricultural Research*. 2017;15:e0603. DOI: <https://doi.org/10.5424/sjar/2017152-9921>
- [5] Oliviero C, Heinonen M, Valros A, Halli O, Peltoniemi OAT. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. *Anim Reprod Sci*. 2008;105:365-377
- [6] 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
- [7] Hoving LL, Soede NM, Feitsma H, Kemp B. Lactation weight loss in primiparous sows: consequences for embryo survival and progesterone and relations with metabolic profiles. *Reprod Domest Anim*. 2012;47:1009-1016
- [8] Costermans NG, Teerds KJ, Middelkoop A, Roelen BA, Schoevers EJ, van Tol HT, Laurensen B, Koopmanschap RE, Zhao Y, Blokland M, van Tricht F, Zak L, Keijer J, Kemp B, Soede NM. Consequences of negative energy balance on follicular development and oocyte quality in primiparous sows. *Biol Reprod*. 2020;102:388-398. DOI: <https://doi.org/10.1093/biolre/ioz175>
- [9] Algers B and Uvnäs-Moberg, K. Maternal behavior in pigs. *Hormones and Behavior*. 2007;52:78-85
- [10] Taverne MAM and van der Weijden GC. Parturition in Domestic Animals: Targets for Future Research. *Reproduction in Domestic Animals*. 2008;48:36-42
- [11] Farmer C. and Quesnel H. Nutritional, hormonal, and environmental effects on colostrum in sows. *J Anim Sci*. 2009;87:56-64. http://jas.fass.org/cgi/content/full/87/13_suppl/56
- [12] Farmer C. Altering prolactin concentrations in sows. *Domestic Animal Endocrinology*. 2016;56:155-164. <http://dx.doi.org/10.1016/j.domaniend.2015.11.005>
- [13] Castren H, Algers B, de Passille AM, Rushen J, Uvnäs-Moberg K. Preparturient variation in progesterone, prolactin, oxytocin and somatostatin in relation to nest-building in sows. *Appl Anim Behav Sci*. 1993;38:91-102
- [14] Oliviero C, Heinonen M, Valros A, Peltoniemi O. Environmental and sow-related factors affecting the duration of farrowing. *Anim Reprod Sci*. 2010;119:85-91
- [15] Kaiser M, Jacobsen S, Haubro-Andersen P, Bækbo P, Cerón J, Dahl J, Escribano D, Jacobson M. Inflammatory markers before and after farrowing in healthy sows and in sows affected with

- postpartum dysgalactia syndrome. BMC Vet Res. 2018;14:83. Doi.org/10.1186/s12917-018-1382-7
- [16] Yun J, Ollila A, Valros A, Larenza Menzies MP, Heinonen M, Oliviero C, Peltoniemi O. Behavioural alterations in piglets after surgical castration: Effects of analgesia and anaesthesia. Research in Veterinary Science. 2019;125:36-42. <https://doi.org/10.1016/j.rvsc.2019.05.009>
- [17] Peltoniemi O, Oliviero C, Yun J, Grahofer A, Björkman S. Management practices to optimize the parturition process in the hyperprolific sow. Journal of Animal Science. 2020;98:96-106
- [18] Björkman S, Oliviero C, Rajala-Schultz PJ, Soede NM, Peltoniemi OA. The effect of litter size, parity and farrowing duration on placenta expulsion and retention in sows. Theriogenology. 2017;92:36-44
- [19] Björkman S, Oliviero C, Kauffold J, Soede NM, Peltoniemi OAT. Prolonged parturition and impaired placenta expulsion increase the risk of postpartum metritis and delay uterine involution in sows. Theriogenology. 2018;106:87-92
- [20] Petersen HH, Nielsen JP, Heegaard PM. Application of acute phase protein measurements in veterinary clinical chemistry. Vet Res. 2004;35:163-187. doi:10.1051/vetres:2004002
- [21] Coleman DN, Lopreiato V, Alharthi A, Looor JJ. Amino acids and the regulation of oxidative stress and immune function in dairy cattle. Journal of Animal Science. 2020;98,1:175-193. DOI:10.1093/jas/skaa138
- [22] Larsen I, Thorup F. The diagnosis of MMA. Proc Int Pig Vet Soc. 2006;52:256
- [23] Papadopoulos GA, Vanderhaeghe C, Janssens GPJ. Vet J. 2010;184:167-171
- [24] Bäckström L, Morkoc AC, Connor J, Larson R, Price W. J Am Vet Med Assoc. 1984;185:70-73
- [25] Peltoniemi OAT, Björkman S and Maes D. Reproduction of group-housed sows. Porcine Health Management. 2016;2:15. DOI: 10.1186/s40813-016-0033-2
- [26] Kemper N. Update on postpartum dysgalactia syndrome in sows. Journal of Animal Science. 2020;98:1. DOI: 10.1093/jas/skaa135
- [27] Farmer C, Maes D, Peltoniemi OAT. The mammary system. In: Zimmerman J, Karriker L, Ramirez A, Schwartz K, Stevenson G, Zhang J, editors. Diseases of swine, 11th ed. USA: Wiley Blackwell, 2019. p. 313-338
- [28] Han T, Björkman S, Soede NM, Oliviero C, Peltoniemi O. IGF-1 concentration patterns and their relationship with follicle development after weaning in young sows fed different pre-mating diets. Animal. 2020;14:1493-1501. DOI: 10.1017/S1751731120000063
- [29] Han T, Björkman S, Soede NM, Oliviero C, Peltoniemi O. Insulin-like growth factor-1 concentrations indicate a rapid metabolic recovery after weaning of young sows fed different premating diets. Animal. 2020 accepted for publication
- [30] Han T, Björkman S, Soede NM, Oliviero C, Peltoniemi O. Effect of IGF-1 level at weaning on subsequent luteal development and progesterone production in primiparous sows. In: Abstract book 11th European Symposium of Porcine Health Management; 22-24 May. Utrecht. The Netherlands: ESPHM; 2019. p. 82-82
- [31] Almiñana C, Corbin E, Tsikis G, Alcântara-Neto AS, Labas V, Reynaud K, Galio L, Uzbekov R, Garanina AS, Druart X, Mermillod P. Oviduct

extracellular vesicles protein content and their role during oviduct–embryo cross-talk. *Reproduction*. 2017;154:253-268. DOI: 10.1530/REP-17-0054

[32] Rooke JA, Bland IM. The acquisition of passive immunity in the new-born piglet. *Production Science*. 2002;78:13-23

[33] Baumgartner, J. Pig industry in CH, CZ, DE, DK, NL, NO, SE, UK, AT and EU [Internet]. Available from: https://www.vetmeduni.ac.at/fileadmin/v/tierhaltung/I-Baumgartner_Pig_industry_in_CH_CZ_DE_DK_NL_NO_SE_UK_AT_and_EU.pdf [Accessed: 2020-09-15]

[34] Kemp B, Da Silva CS, Soede NM. Recent advances in pig reproduction: Focus on impact of genetic selection for female fertility. *Reprod Domest Anim*. 2018;53:28-36

[35] Kobek Thorsen C, Aagaard Schild S, Rangstrup-Christensen L, Bilde T, Juul Pedersen L. The effect of farrowing duration on maternal behavior of hyper-prolific sows in organic outdoor production. *Livestock Science*. 2017;204:92-97

[36] Labroue F, Caugant A, Ligonesche B, Gaudré D. Étude de l'évolution des tétines d'apparence douteuse chez la cochette au cours de sa carrière. *Journées de la Recherche Porcine en France*. 2001;33:145-150

[37] Andersen I, Nevdal E, Bøe K. Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs (*Sus scrofa*). *Behavioral Ecology Sociobiology*. 2011;65:1159-1167

[38] Quesnel H, Brossard L, Valancogne A, Quiniou N. Influence of some sow characteristics on within-litter variation of piglet birth weight. *Animal*. 2008;2:1842-1849

[39] Beaulieu AD, Aalhus JL, Williams NH, Patience JF. Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork. *Journal of Animal Science*. 2010;88:2767-2778

[40] Smit M, Spencer J, Almeida F, Patterson J, Chiarini-Garcia H, Dyck M, Foxcroft G. Consequences of a low litter birth weight phenotype for postnatal lean growth performance and neonatal testicular morphology in the pig. *Animal*. 2013;7:1681-1689. DOI: 10.1017/S1751731113001249

[41] Matheson S, Walling GA, Edwards SA. Genetic selection against intrauterine growth retardation in piglets: a problem at the piglet level with a solution at the sow level. *Genetic Selection Evolution*. 2018; 50:46

[42] Declerck I, Sarrazin S, Dewulf J, Maes D. Sow and piglet factors determining variation of colostrum intake between and within litters. *Animal*. 2017;11:1336-1343

[43] Hoy S, Lutter C, Wähner M, Puppe B. The effect of birth weight on the early postnatal vitality of piglets. *Dtsch Tierarztl Wochenschr*. 1994;101:393-396

[44] Islas-Fabila P, Mota-Rojas D, Martínez-Burnes J, Mora-Medina P, González-Lozano M, Roldan-Santiago P. Physiological and metabolic responses in newborn piglets associated with the birth order. *Animal Reproduction Science*. 2018;197:247-256

[45] Salmon H, Berri M, Gerdts V, Meurens F. Humoral and cellular factors of maternal immunity in swine. *Developmental and Comparative Immunology*. 2009;33:384-393. doi: 10.1016/j.dci.2008.07.007

- [46] Theil PK, Lauridsen C, Quesnel H. Neonatal piglet survival: impact of sow nutrition around parturition on fetal glycogen deposition and production and composition of colostrum and transient milk. *Animal*. 2014;8:1021-1030
- [47] Quesnel H, Farmer C, Devillers N. Colostrum intake: Influence on piglet performance and factors of variation. *Livest Sci*. 2012;146:105-114
- [48] Lessard M, Blais M, Beaudoin F, Deschene K, Lo Verso L, Bissonnette N, Lauzon K, Guay F. Piglet weight gain during the first two weeks of lactation influences the immune system development. *Veterinary Immunology and Immunopathology*. 2018;206:25-34. DOI: <https://doi.org/10.1016/j.vetimm.2018.11.005>
- [49] Gimsa U, Tuchscherer M, Kanitz E. Psychosocial Stress and Immunity-What Can We Learn From Pig Studies? *Frontiers in Behavioral Neuroscience*. 2018;12:64. DOI: 10.3389/fnbeh.2018.00064
- [50] Baxter EM, Rutherford KMD, D'Eath RB, Arnott G, Turner SP, Sandøe P, Moustsen PA, Thorup F, Edwards SA and Lawrence AB. The welfare implications of large litter size in the domestic pig II: management factors. *Animal Welfare*. 2013;22:219-238
- [51] Rutherford KM, Baxter EM, D'Eath RB, Turner SP, Arnott G, Roehe R, Ask B, Sandøe P, Moustsen VA, Thorup F, Edwards SA, Berg P, Lawrence AB. The welfare implications of large litter size in the domestic pig I: Biological factors. *Animal Welfare*. 2013;22:199-218
- [52] Kielland C, Rootwelt V, Reksen O, Framstad T. The association between immunoglobulin G in sow colostrum and piglet plasma. *Journal of Animal Science*. 2015;93:4453-4462
- [53] Kapell D, Ashworth CJ, Knap PW, Roehe R. Genetic parameters for piglet survival, litter size and birth weight or its variation within litter in sire and dam lines using Bayesian analysis. *Livestock Science*. 2011;135:215-224
- [54] Quiniou N, Dagorn J, Gaudré D. Variation of piglets' birth weight and consequences on subsequent performance. *Livest Production Sci*. 2002;78:63-70
- [55] Declerck I, Dewulf J, Sarrazin S, Maes D. Long-term effects of colostrum intake in piglet mortality and performance. *J Anim Sci*. 2016;94:1633-1643
- [56] Ferrari C, Sbardella P, Bernardi M, Coutinho M, Vaz I, Wentz I, Bortolozzo F. Effect of birth weight and colostrum intake on mortality and performance of piglets after cross-fostering in sows of different parities. *Preventive Veterinary Medicine*. 2014;114:259-266
- [57] Le Dividich J, Charneca R, Thomas F. Relationship between birth order, birth weight, colostrum intake, acquisition of passive immunity and pre-weaning mortality of piglets. *Spanish Journal of Agricultural Research*. 2017;15:e0603. DOI: <https://doi.org/10.5424/sjar/2017152-9921>
- [58] Nguyen K, Cassar G, Friendship RM, Hodgins D. An investigation of the impacts of induced parturition, birth weight, birth order, litter size, and sow parity on piglet serum concentrations of immunoglobulin G. *Journal of Swine Health and Production*. 2013;21:139-143
- [59] Moreira LP, Menegat MB, Barros GP, Bernardi ML, Wentz I, Bortolozzo FP. Effects of colostrum, and protein and energy supplementation on survival and performance of low-birth-weight piglets. *Livest Sci*. 2017;202:188-193

- [60] Cabrera R, Lin X, Ashwell M, Moeser A, Odle J. Early postnatal kinetics of colostral immunoglobulin G absorption in fed and fasted piglets and developmental expression of the intestinal immunoglobulin G receptor. *Journal of Animal Science*. 2013;91:211-218
- [61] Klobasa F, Werhahn E, Butler JE. Composition of sow milk during lactation. *J Anim Sci*. 1987;64:1458-1466
- [62] Cabrera RA, Lin X, Campbell JM, Moeser AJ, Odle J. Influence of birth order, birth weight, colostrum and serum immunoglobulin G on neonatal piglet survival. *Journal of Animal Science and Biotechnology*. 2012;3:42
- [63] Manjarin R, Montano YA, Kirkwood RN, Bennet DC, Petrovski KR. Effect of piglet separation from dam at birth on colostrum uptake. *Canadian journal of veterinary research*. 2018;82:239-242
- [64] Ji Y, Li H, Xie P, Li Z, Li H, Yin Y, Blachier F, Kong X. Stages of pregnancy and weaning influence the gut microbiota diversity and function in sows. *J Appl Microbiol*. 2019;27:867-879. DOI: 10.1111/jam.14344
- [65] Hasan S, Junnikkala S, Peltoniemi O, Paulin L, Lyyski A, Vuorenmaa J, Oliviero C. Dietary supplementation with yeast hydrolysate in pregnancy influences colostrum yield and gut microbiota of sows and piglets after birth. *PLoS ONE*. 2018;13:e0197586. DOI: <https://doi.org/10.1371/journal.pone.0197586>
- [66] Kim HB, Borewicz K, White BA, Singer RS, Sreevatsan S, Tu ZJ, Isaacson RE. Longitudinal investigation of the age-related bacterial diversity in the feces of commercial pigs. *Vet Microbiol*. 2011;153:124-133
- [67] Jost T, Lacroix C, Braegger C, Chassard C. Stability of the maternal gut microbiota during late pregnancy and early lactation. *Curr Microbiol*. 2014;68:419-427
- [68] Feng ZM, Li TJ, Wu L, Xiao DF, Blachier F, Yin YL. Monosodium L-glutamate and dietary fat differently modify the composition of the intestinal microbiota in growing pigs. *Obes Facts*. 2015;8:87-100
- [69] Hasan, S., Saha, S., Junnikkala, S., Orro, T., Peltoniemi, O., Oliviero, C., 2018. Late gestation diet supplementation of resin acid-enriched composition increases sow colostrum immunoglobulin G content, piglet colostrum intake and improve sow gut microbiota. *Animal*. 2018;27:1-8. DOI: 10.1017/S1751731118003518
- [70] Menegat M, DeRouche J, Woodworth J, Dritz S, Tokach M, Goodband R. Effects of *Bacillus subtilis* C-3102 on sow and progeny performance, fecal consistency, and fecal microbes during gestation, lactation, and nursery periods. *Journal of Animal Science*. 2019;97:3920-3937. DOI: <https://doi.org/10.1093/jas/skz236>
- [71] Tan C, Wei H, Ao J, Long G, Peng J. Inclusion of Konjac Flour in the gestation diet changes the gut microbiota, alleviates oxidative stress, and improves insulin sensitivity in sows. *Appl Environ Microbiol*. 2016;82:5899-5909
- [72] Li H, Liu Z, Lyu H, Gu X, Song Z, He X, Fan Z. Effects of dietary inulin during late gestation on sow physiology, farrowing duration and piglet performance. *Anim Reprod Sci*. 2020;219:106531
- [73] Xu C, Peng J, Zhang X, Peng J. Inclusion of soluble fiber in the gestation diet changes the gut microbiota, affects plasma propionate

and odd-chain fatty acids levels, and improves insulin sensitivity in sows. *Int J Mol Sci.* 2020;21:635

[74] Sassone-Corsi M, Raffatellu M. No vacancy: How beneficial microbes cooperate with immunity to provide colonization resistance to pathogens. *J Immunol.* 2015;194:4081-4087

[75] Liu P, Piao XS, Kim SW, Wang L, Shen YB, Lee HS, Li SY. Effects of chito-oligosaccharide supplementation on the growth performance, nutrient digestibility, intestinal morphology, and fecal shedding of and in weaning pigs. *J Anim Sci.* 2008;86:2609-2618

[76] Eckburg, P. B., Bik, E. M., Bernstein, C. N., Purdom, E., Dethlefsen, L., Sargent, M. Diversity of the human intestinal microbial flora. *Science.* 2005;308: 1635-1638. DOI: 10.1126/science.1110591

[77] Morgan XC, Tickle TL, Sokol H, Gevers D, Devaney KL, Ward DV. Dysfunction of the intestinal microbiome in inflammatory bowel disease and treatment. *Genome Biol.* 2012;13:79. DOI: 10.1186/gb-2012-13-9-r79

[78] Koren O, Goodrich JK, Cullender TC, Spor A, Laitinen K, Bäckhed HK. Host remodeling of the gut microbiome and metabolic changes during pregnancy. *Cell.* 2012;150:470-480. DOI: 10.1016/j.cell.2012.07.008

[79] Shin NR, Whon TW, Bae JW. Proteobacteria: microbial signature of dysbiosis in gut microbiota. *Trends Biotechnol.* 2015;33:496-503. DOI: 10.1016/j.tibtech.2015.06.011

[80] Litvak Y, Byndloss MX, Tsolis RM, Bäumler AJ. Dysbiotic Proteobacteria expansion: a microbial signature of epithelial dysfunction. *Curr. Opin. Microbiol.* 2017;39:1-6. DOI: 10.1016/j.mib.2017.07.003

[81] Peltoniemi O, Björkman S, Oropeza-Moe M, Oliviero C. Developments of reproductive management and biotechnology in the pig. *Animal Reproduction.* 2019;16:524-538. DOI: 10.21451/1984-3143-AR2019-0055