

1 **Management practices to optimize the parturition process in the hyperprolific sow**

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16 Review-ICPD 2019

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19 **Abstract**

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

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

44

#### 45 **Consequences of increased litter size**

46

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

60

61 An uncomplicated vaginal delivery of foetuses involves timely contractions of the uterine structures  
62 (Oscarsson et al., 2006; Berglund et al., 2008; Taverne and van den Weijden, 2008; Senger, 2012).

63 While contractions are good in terms of the actual expulsion of the foetuses, they result in  
64 vasoconstriction of placental circulation, and ultimately rupture of the umbilical cord, exposing  
65 foetuses still within the uterus to oxidative stress. In the longer run, this leads to hypoxia (Oscarsson  
66 et al., 2006; Berglund et al., 2008; Taverne and van den Weijden, 2008; Boksa et al., 2015). If

67 foetuses are subjected to hypoxia during the birth process, they are much more likely to be  
68 hypoglycaemic, less alert, and under increased risk of being crushed by the dam (Oliviero, 2013).  
69 This may indeed present a problem when very large litters are in the process of being born.  
70 Furthermore, these extra large litters also hold the risk of decreased piglet birth weight (Akdag et  
71 al., 2009; Beaulieu et al., 2010) and increased rate of intra-uterine growth retardation (IUGR)  
72 (Matheson et al., 2018; Oliviero et al., 2019). Such IUGR piglets are not only immature in terms of  
73 their immunity, but they are less active and need more time to achieve the first suckle. Furthermore,  
74 the ability of the sow to provide a reliable source of colostrum for all piglets may reach a limit, as  
75 the number of piglets approaches or even surpasses the number of functional teats (Spinka and  
76 Illmann, 2015). The window for access to colostrum is also shortened through prolonged farrowing  
77 in the hyper-prolific sows (Oliviero et al., 2019). Therefore, colostrum intake per piglet decreases  
78 with increasing litter size. An estimated 35% of sows do not produce enough colostrum to  
79 adequately supply all of their piglets (Quesnel et al., 2012). As a result, low birth weight piglets in  
80 large litters are at a greater risk of not obtaining at least 200-250 g of colostrum (Quesnel et al.,  
81 2012; Hasan et al., 2019), which is the amount needed for adequate immunoglobulin levels and  
82 minimum growth (Spinka and Illmann, 2015).

83

84 Another major problem that arises from extra large litters is an increased incidence of diseases of  
85 the udder and the uterus, resulting in decreased reproductive performance of the sow. Prior to  
86 parturition, hyper-prolific sows need to be fed according to the number of developing foetuses. This  
87 led to increases in the amounts of energy and feed provided to gestating sows. However, a greater  
88 volume of feed ingested in gestation is known to be a risk factor for the metabolism of  
89 periparturient sows, likely creating a negative energy balance (Feyera et al., 2018; Farmer et al.,  
90 2019). Increasing the volume of feed, and thus energy, is also a risk factor for constipation and poor  
91 mammary gland development (Farmer and Quesnel, 2009; Oliviero et al., 2010; Farmer and Hurley,

92 2015; Farmer et al., 2019), leading to insufficient colostrum and milk production and, therefore, low  
93 piglet survival and development (Edwards and Baxter, 2015).

94 After parturition, prolonged farrowing may be manifested as adverse development of microbiota in  
95 the sow (Hasan et al., 2018b). This may be due to the birth canal staying open for extended periods  
96 of time (Peltoniemi et al., 2019a). It is therefore not surprising that in hyperprolific sows a greater  
97 incidence of uterine problems and placental expulsion have been reported (Björkman et al., 2017a)  
98 as well as increased rate of uterine inflammation giving rise to postpartum dysgalactia (PDS,  
99 Björkman et al., 2018c). It was recently reported that the incidence of PDS has increased along with  
100 litter size, reaching the current value of 34% in the DanBred breed (Kaiser et al., 2018a;b).

101 Therefore, the problems related to prolonged farrowing, which are highly associated with the  
102 hyperprolific sow (Oliviero et al., 2019), warrant careful consideration in future management and  
103 breeding. It is hypothesized that with optimal management the duration of farrowing may be  
104 decreased, improving the prospects for newborn piglets. However, cross breeding of the modern  
105 highly prolific sow lines back with the less productive but more robust breeds may be needed to  
106 cope with the evolving challenges. The following text will cover the management practices  
107 currently available for successful farrowing, reduction of duration of farrowing, optimization of  
108 colostrum production and intake by piglets, favourable changes in microbiota in piglets and sows,  
109 and a decrease in diseases such as PDS that affect the udder and the uterus.

110

### 111 **Diagnosis of abnormal parturition**

112

### 113 **Behaviour during the first and second stages of parturition**

114 The first stage of parturition overlaps with the time period of nest-building behaviour, which is a  
115 highly expressed, intrinsic behaviour of the pig occurring during the last 24 hours prior to the onset  
116 of the expulsion stage (Jensen, 1986; Algers and Uvnäs-Moberg, 2007). Nest-building activity is at

117 its peak between 6 and 12 hours preceding the expulsion of the first piglet (for reviews, see  
118 Lawrence et al., 1997; Wischner et al., 2009). If space and materials for nest-building are lacking,  
119 sows may redirect the need for nest-building to other types of activities, giving rise to greater  
120 overall activity level during parturition. Thodberg et al. (2002) found that sows housed in pens  
121 without nesting materials expressed less nest-building behaviour and an increased frequency of  
122 attempts to express nest-building prior to the onset of expulsion of piglets. However, more nest-  
123 building like behaviour was observed in pens without nesting material during the expulsion  
124 (second) stage of parturition compared with pens provided with straw (Thodberg et al., 2002).  
125 Alternatively, inhibition of the expression of nest-building behaviour prior to the second stage of  
126 parturition by lack of space and substrates may provoke a stress response in sows. The stress  
127 response may then result in increased behavioural activities during parturition, thus delaying the  
128 farrowing process (for review, see Yun and Valros, 2015). The occurrence of prepartum nest-  
129 building behaviour was shown to be positively correlated with increased litter size (Pedersen et al.,  
130 2006). Therefore, providing optimal farrowing environment with adequate space and nesting  
131 materials appears particularly important for the hyper-prolific sow. It can encourage the  
132 performance of nest-building during the first stage of parturition. A supportive environment may  
133 therefore decrease stress and shorten the second stage of parturition.

134 After entering the second stage of parturition, postural changes decrease and duration of lying  
135 gradually increases (Figure 2). Harris and Gonyou (1998) proposed that frequent postural changes  
136 or restlessness can be indicative of the state of discomfort in peripartum gilts. Furthermore, our  
137 previous findings (Yun et al., 2019) suggested that suboptimal farrowing environments for sows  
138 with a large litter may cause considerable stress. The increased stress appears to induce a greater  
139 frequency of postural changes and longer duration of standing position of sows during the expulsion  
140 stage of parturition (Yun et al., 2019). Stress and discomfort of sows can therefore be suspected

141 when there are no signs of cessation of activities such as nest–building in the beginning of the  
142 second stage of parturition.

143

#### 144 **Prolonged second and third stages of farrowing**

145 Only a decade ago, a farrowing duration of more than five hours and a piglet birth interval longer  
146 than 25 minutes were considered excessively long farrowing (Oliviero, 2010). With the avenue of  
147 hyperprolific sows, the average farrowing duration has considerably increased. In fact, in Danish  
148 sows, the average duration of farrowing was recently reported to be 7 to 7,5 hours (Hales et al.,  
149 2015; Thorsen et al., 2017). Hence, it is important to recognize the signs of a prolonged farrowing  
150 both during the process and immediately after it. It is often recommended that the sow should be  
151 supervised and, if necessary, assisted during farrowing (Kirkden et al., 2013). Signs of prolonged  
152 farrowing could include restless behaviour, as discussed above, and strong abdominal straining due  
153 to acute obstructive dystocia (Cowart, 2007). On the other hand, weak or absent abdominal  
154 contractions in a calm sow most likely refer to uterine inertia. Dystocia in sows is relatively rare  
155 compared with other livestock species, but this condition has increased over the years from 0.5% to  
156 5%, with an even higher incidence in modern hyperprolific sow lines (Jones, 1966; Randall, 1972;  
157 Peltoniemi et al., 2019a). In the past, when litter size was not so large, uterine inertia was  
158 considered mainly to be secondary due to fatigue of dystocia (Almond et al., 2006). On the other  
159 hand, large litters are nowadays the likely primary cause of uterine inertia due to a heavy and  
160 overstretched uterus and hormonal disturbances in the sow. Thus, prevention of prolonged  
161 parturition in hyperprolific sows is essential and will be discussed later in more detail.

162

163 If preventive measures fail to be successful, sows need more intense monitoring at farrowing. For  
164 instance, sows that are obese or show constipation during the days before expected farrowing  
165 should be monitored more carefully. Constipation and presence of excessive faecal material in the

166 colon and rectum may result in partial occlusion of the birth canal (Coward, 2007). One study  
167 reported an increase in farrowing duration associated with clinical constipation during the five days  
168 prior to farrowing (Oliviero et al., 2010). Another sign of prolonged farrowing is expulsion of the  
169 placenta during the second stage of birth. If the placenta is expelled before the last piglet, it is likely  
170 that parturition has been ongoing for more than five hours (Björkman et al., 2017a). On the other  
171 hand, expulsion of minor parts of the placenta or absence of placental expulsion after the last piglet  
172 is born may also be a sign of prolonged parturition. This may indicate a substantial slowing of the  
173 birth process (Björkman et al., 2017a). In summary, while litter size has doubled in the past three  
174 decades, duration of farrowing has increased by 4 to 5 times, hence presenting a great challenge for  
175 the pig industry.

#### 176 **Colostrum quality**

177 Several studies report that 200 to 250 g of colostrum per piglet is the minimum requirement to  
178 induce sufficient immune protection (Devillers et al., 2007; Quesnel, 2011; Hasan et al., 2019).  
179 Colostrum production lasts only 16 to 24 hours after parturition starts, and already after the first 6  
180 hours the IgG content in colostrum is halved (Le Dividich et al., 2005). However, by the sixth hour,  
181 there is still an average of 20% piglets still within the uterus in the hyper prolific sow (Oliviero et  
182 al., 2019) Those piglets miss out on access to colostrum of good quality. Therefore, especially when  
183 managing large litters, determination of the level of immunoglobulins in colostrum could be a  
184 useful tool. Hasan et al. (2016) proposed the use of the Brix refractometer to evaluate sow  
185 colostrum content of IgG on the farm. The IgG content in sows peaks shortly after the onset of  
186 farrowing, with reported concentrations 60 to 70 mg/mL at this time (Hurley, 2015; Quesnel, 2015).  
187 However, concentrations decrease to around 10 mg/ml at the end of colostrogenesis (24 h after the  
188 onset of farrowing). Colostrum should be tested with the Brix refractometer at the beginning of  
189 farrowing (0 to 3 h) when it is easiest to collect and when concentrations of IgG are expected to be  
190 near the peak values for this time period (Hasan et al., 2016). The authors considered an IgG

191 content of 50 mg/mL as a fairly safe cut-off point to provide adequate amounts of IgG to newborn  
192 piglets. A table for evaluation of the Brix refractometer results is shown in Table 1. When Brix  
193 values are <20%, they reflect very low levels of IgG, while values from 25% upwards are  
194 considered to correspond to adequate or very good concentrations of IgG in colostrum. Values  
195 between 20% and 24% are defined as borderline, yet they should only be considered critical if  
196 within the lowest range of this category (20% to 21%). Therefore, with borderline results, the  
197 authors suggest taking another sample within 1 to 2 hours to determine whether the estimated IgG  
198 content is stable, increasing, or decreasing compared to the initial value. Using colostrum Brix  
199 measurement at farm level may help to identify sows with impaired IgG concentrations in early  
200 parturition. In conclusion, the Brix refractometer could be used to increase stockmanship with large  
201 litters by routinely screening the colostrum quality of sows in the herd in order to detect  
202 unfavourable low levels of IgG as result of feeding, diseases, or management issues.

203

204

### 205 **Ultrasonography and other biomarkers**

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

216 After parturition is completed, ultrasound is beneficial to determine uterine health. The timely and  
217 correct diagnosis of postpartum uterine disease is essential to prevent postpartum dysgalactia  
218 syndrome, hence, decreased neonatal development and survival as well as decreased subsequent  
219 fertility of the sow (Kauffold and Wehrend, 2014). Ultrasonography is considered to be the best tool  
220 for diagnosis of endometritis and retained placenta (Björkman et al., 2018c; Kauffold et al., 2019).  
221 Examination of uterine structures currently utilizes three criteria: fluid echogenicity, echotexture,  
222 and size (Kauffold and Althouse, 2007; Peltoniemi et al., 2016; Björkman 2017c). Increased size  
223 and echotexture are a reflection of oedema changes in the endometrium, which is usually abnormal.  
224 Nevertheless, the parity of the sow and the postpartum day on which the examination is performed  
225 need to be taken into consideration when interpreting uterine size. Furthermore, any fluid causing  
226 echogenicity must be considered abnormal and indicative of an exudative inflammation of an acute  
227 or acute-chronic type (Kauffold and Althouse, 2007). Fluid echogenicity is often associated with  
228 increased echotexture and size of uterine cross-sections (Björkman et al., 2018c), therefore sharing  
229 similar risk factors. These risk factors are prolonged parturition, obstetric intervention, placental  
230 retention, and birth of two or more stillborn piglets (Björkman et al., 2018c). Postpartum ultrasound  
231 can be used to diagnose retention of the placenta (Peltoniemi et al., 2016; Björkman et al., 2017a,  
232 2017c; Kauffold et al., 2019).

233  
234 Besides ultrasonography, other biomarkers have been extensively used to evaluate health status,  
235 establish a diagnosis or prognosis of the disease, predict and/or monitor response to therapy, and  
236 assess reproductive failure (Myers et al., 2017). Characteristics related to clinical signs such as  
237 vaginal discharge, total amount, colour, number of cells, and cell characteristics, are considered as  
238 biomarkers that are used to evaluate uterine health, but different variables are needed to strengthen a  
239 presumptive diagnosis of endometritis in sows after birth (Grafofer et al., 2019). As cystitis is one  
240 of the main risk factors for sows showing sustained uterine infections (Biksi et al., 2002), several

241 useful biomarkers are described in the literature (Kauffold et al., 2010; Bellino et al., 2013;  
242 Grahofer et al., 2014; Sipos et al., 2014). Midstream urine samples are often contaminated through  
243 the environment, and therefore sterile urine or swabs from the bladder of culled sows should be  
244 tested and a culture performed if there are problems with the urinary tract in a sow herd (Grahofer et  
245 al., 2014; Sipos et al., 2014). Ultrasonography of the urinary bladder is inappropriate for the  
246 diagnosis of urinary tract infections in sows because the variables are dependent on filling of the  
247 urinary bladder. Only moderate to high amounts of sediment seem to be indicative of cystitis  
248 (Kauffold et al., 2010). Hence, a combination of several variables is necessary to diagnose  
249 infections of the urogenital tract in sows. In conclusion, ultrasonography with modern equipment  
250 appears to be a good tool to efficiently follow-up on the health status of the birth canal, uterus, and  
251 urinary tract in postpartum sows.

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#### 254 **Treatment of abnormal parturition**

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

266           **Treatment of prolonged parturition**

267   The role of biosecurity and expert level stockmanship are of highest value in obstetric interventions.  
268   Appropriate and prompt treatment of the sow during prolonged parturition is important to avoid  
269   negative effects on the sow's reproductive health and the piglets' health and survival. This can be  
270   achieved through continuous farrowing supervision (Holyoake et al., 1995). In general, obstetric  
271   intervention is indicated if more than 45 minutes have passed since the last piglet was expelled  
272   (Peltoniemi et al., 2019a). This especially applies if the sow is restless and has strong abdominal  
273   contractions or if parturition is prolonged beyond 300 minutes (Oliviero et al., 2008). If the sow is  
274   still at the beginning of parturition and shows no signs of discomfort or strong abdominal straining,  
275   obstetric intervention is usually not indicated before one hour has passed since the last piglet was  
276   born (Peltoniemi et al., 2019a). Most often maternal causes, such as secondary uterine inertia, lead  
277   to dystocia in sows. Nevertheless, general and obstetric examinations, including palpation and  
278   ultrasonography of the birth canal, are necessary to rule out other causes of dystocia, such as  
279   obstruction of the birth canal, ventral deviation of the uterine horns, or foetal malposition, before  
280   treating for uterine inertia (Peltoniemi et al., 2019a). Oxytocin provokes uterine contractions and it  
281   is frequently used during farrowing to treat dystocia (Straw et al., 2000). Use of oxytocin is only  
282   indicated when there is no obstruction of the birth canal, the piglet is well positioned, and the sow  
283   has poor uterine contractions (Gilbert, 1999). Before administration of any exogenous oxytocin, it is  
284   recommended to try means of releasing endogenous oxytocin, e.g. manual induction of the  
285   Ferguson reflex through stimulation of the cervix or encouraging the sow to move, especially if the  
286   sow is still at the beginning of the second phase of parturition. Nevertheless, if secondary uterine  
287   inertia is diagnosed towards the end of the second phase of parturition, immediate injection of  
288   oxytocin is indicated (Peltoniemi et al., 2019a). Several studies were conducted to prove the effect  
289   of oxytocin on the birth process and piglet survivability and to evaluate the proper dosage of  
290   oxytocin in dystotic sows (Mota-Rojas et al., 2002; 2005a,b; 2007). An intramuscular

291 administration of 10 IU of oxytocin did not cause any side effects. However, higher dosages (20 to  
292 50 IU) led to an increase in stillborn piglets, changes in the umbilical cord, and greater meconium  
293 scoring (Mota-Rojas et al., 2002, 2005a,b, 2007; Kaeoket, 2006). Furthermore, improper use of  
294 oxytocin can increase uterine inertia (Dial et al. 1987). Hence, oxytocin should be only restrictively  
295 administered, e.g. a maximum of 10 IU one to two times during parturition. Recently, two studies  
296 investigated the use of carbetocin, a long-acting analogue of oxytocin, administered routinely after  
297 expulsion of the first piglet (Jiarpinitnun et al.,2019; Ward et al., 2019). Their findings indicated  
298 that while use of carbetocin may reduce duration of farrowing, it can also reduce colostrum yield  
299 and increase still born rate. Another study reported severe undesirable side effects after routine  
300 administration of 35 µg of carbetocin during the farrowing process in a free farrowing system  
301 (Grafofer et al.,2019). A prolonged piglet-to-piglet birth interval directly after application, loss of  
302 colostrum, and increased number of weak and stillborn piglets were also detected. Therefore,  
303 administration of carbetocin is not currently recommended to improve the birth process. In  
304 conclusion, timely application of birth assistance, considering behaviour of the sow and the time  
305 elapsed since start of parturition, has become more important than ever in hyperprolific sows.  
306 Hyper-stimulation of the uterus with excessive oxytocin must, however, be avoided. In addition,  
307 breeding goals of pig production should be re-examined for robustness and resilience.

308

### 309 **Improving colostrum uptake**

310 Once piglets are born, farmers need to quickly implement a strategy to reduce piglet mortality. This  
311 is important especially in large litters which have greater incidences of low-viability piglets and  
312 where competition for colostrum and milk access are increased (Lund et al., 2002; Devillers et al.,  
313 2011; Hasan et al., 2019). To provide all piglets with sufficient individual colostrum intake (200 to  
314 250 g) within 12 to 16 hours from the beginning of parturition, different strategies can be adopted.  
315 When possible, small and low-viable piglets should be assisted to suckle, helping them to attach to

316 the teat, and ensuring that they are able to ingest colostrum. Baxter et al. (2008) investigated  
317 behavioural and physiological indicators of neonatal survival and provided data that could be used  
318 to identify piglets in need of assistance (Table 2). Besides birth weight and crown-rump length,  
319 survival of piglets was positively related with rectal temperature between birth and 24 hours  
320 postpartum and with vitality score, rooting response, and latency to access a teat and suckle. These  
321 traits were also correlated with each other, showing the importance of prevention of the  
322 hypothermia-starvation-crushing complex in neonatal piglets, as summarized by Edwards and  
323 Baxter (2015). Those authors concluded that a piglet needs to be assisted to suckle if the following  
324 criteria are met: vitality of less than 2, meaning no movements within 15 seconds of birth, latency to  
325 access and suckle a teat of more than 30 minutes, and rectal temperature of less than 37°C during  
326 the first hour after birth. This may, however, be difficult to put into practice and it may be helpful to  
327 make use of thermal images to overcome these difficulties (Alexopoulos et al. 2018). As is the case  
328 with body temperature, skin temperature is linked to birth weight, vitality, and colostrum ingestion  
329 and can be used to determine whether a piglet has reached a teat, suckled, and ingested colostrum  
330 within 30 minutes of birth (Santiago et al., 2019; Zhang et al., 2019a). As a piglet begins to suck  
331 and ingest colostrum, energy and warmth are provided, increasing rectal and skin temperatures  
332 (Figure 3; Alexopoulos et al., 2018). If skin temperature drops below 30°C, the piglet has not been  
333 successful in suckling (Figure 3; Alexopoulos et al., 2018) and needs to be assisted to attach to the  
334 teat and ensure that it ingests colostrum. The digital measurements such as digital skin temperature  
335 in Figure 3 may be part of automated supervision of farrowing, which appears as an important and  
336 cost-effective part of future management of parturition. It is important to remember that small  
337 piglets have difficulties in suckling from teats with big nipples, and therefore, the smallest  
338 functioning nipples should be preferred when assisting suckling. This procedure should be repeated  
339 3 to 4 times within the first few hours if these piglets are not seen to actively suckle at the udder.  
340 Additionally, low-viable piglets can be hand-fed with colostrum collected from their mother or

341 other sows within 6 to 12 hours from the beginning of farrowing. Assisted suckling and hand  
342 feeding work well in small to normal litters with only one or two small piglets. In large litters and  
343 litters with more than two low-viable piglets, a split-suckling strategy could be more effective  
344 (Oliviero, 2013). To minimize sibling competition for colostrum intake, the litter is split into two  
345 groups. The more vigorous piglets with a full stomach are kept in the creep area or in a separate  
346 box, allowing the other piglets to suckle for 60 to 90 minutes, and then the groups are switched  
347 (Oliviero, 2013). This process is repeated as many times as possible. When separating the piglets,  
348 both groups should always have free access to a warm creep area. If some small piglets are still  
349 unable to successfully suckle, assisted suckling should be combined with split-suckling. In  
350 conclusion, litters from hyperprolific sows require close attention and assistance must be provided  
351 to late-born piglets, piglets without successful access to a teat, as well as underweight and less  
352 active piglets. New technology, such as the use of infrared cameras, may be utilized to assess the  
353 status of the newborn piglets.

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## 357 **Prevention**

### 358 **Feeding and mammary gland development**

359 Adequate mammary gland development is important for optimal colostrum and milk production and  
360 this topic has been recently reviewed by Farmer and Hurley (2015). In terms of mammary gland  
361 development and ease of farrowing, ad-libitum feeding with low fibre high energy feed in the last  
362 third of gestation should be avoided and more attention should be directed to feed composition.  
363 Providing the right amount of crude fibre and an adequate uptake of crude protein and certain  
364 essential amino acids are important (Farmer and Hurley, 2015). Interestingly, restricted feeding  
365 (about 50%) during the last third of gestation seems to be beneficial since backfat loss in that period

366 has been positively associated with colostrum yield (Decaluwe et al., 2013). Yet, this can only be  
367 recommended for sows in good body condition in order to achieve optimal body condition (Oliviero  
368 et al., 2010) and mammary development (Farmer et al., 2016) at parturition. These studies suggest  
369 that more than 16 mm of backfat should be achieved, while also avoiding over conditioning.  
370 However, one must ensure that gestating sows receive sufficient energy to satisfy the demands of  
371 the forthcoming lactation, hence, sows are usually fed with high-energy concentrated lactation diets  
372 during late gestation (Einarsson and Rojkittikhun, 1993). Such concentrated diets, which contain  
373 less fibre than standard pregnancy diets (at least 7% crude fibre), can promote obesity and  
374 constipation. These two conditions are associated with prolonged farrowings and an increased  
375 stillbirth rate (Oliviero et al., 2010). Late pregnancy diets should contain up to 7 to 10% crude fibre  
376 in order to reduce constipation and excessive fat depots (Oliviero et al., 2009). If the diet cannot be  
377 easily modified, a good fibre source can be provided by offering different types of roughage (straw,  
378 hay) or adding any other feedstuffs with high levels of fibre, such as sugar beet pulp (Quesnel et al.,  
379 2009). The provision of roughage may not only be a way of increasing fibre intake and alleviating  
380 constipation and obesity, but can also serve as an appropriate material for nest - building. Proper  
381 nest-building behaviour is linked to lower concentrations of progesterone and greater concentrations  
382 of prolactin prepartum (Algers and Uvnäs-Moberg 2007). A high prepartum prolactin to  
383 progesterone ratio is also needed for adequate colostrum production (Foisnet et al., 2010). In  
384 addition, the use of dietary fibre can promote a better colostrum yield (Foisnet et al., 2010). Feeding  
385 fibre to gestating sows can also influence their gut microbiota, increasing the number of bacteria  
386 that are able to breakdown and ferment complex carbohydrates into short-chain fatty acids (SCFAs,  
387 Jha et al., 2019). The SCFAs produced by bacteria are thought to provide up to 30% of the  
388 maintenance energy requirement of gestating sows (Varel and Yen, 1997). Moreover, an increase in  
389 the concentration of SCFAs, more specifically butyrate, can improve gut mucosal health and the  
390 immune system of pigs. A recent study reported that an increased amount of cellulolytic bacteria

391 such as *Paraprevotella and Roseburia* in the gut of sows was correlated with greater colostrum  
392 production (Hasan et al., 2018a). Moreover, the mother can influence the gut microbiota of her  
393 piglets, which was shown to improve piglet growth performance (Hasan et al., 2018a; Cheng et al.,  
394 2018). Another avenue that was recently investigated is the sow glucose metabolism shortly before  
395 and during the expulsion stage of farrowing. More specifically, Feyera et al. (2018) found that a  
396 short time lapse (less than 3 hours) between the last meal and the onset of the expulsion stage  
397 shortened the duration of farrowing. Therefore, it appears that modifying the sow's late gestation  
398 diet as well as providing the sow with frequent access to feed prior to farrowing can have beneficial  
399 effects on colostrum production and health of the sow, and on piglet growth.

400

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

416 visually or with the aid of ultrasound, and a tissue sample by biopsy is also possible (Björkman et  
417 al., 2017b; 2018a, 2018b; Han et al., 2018). It is important to keep in mind that the number of teats  
418 and teat morphology are factors that should be considered in farrowing management.

419

#### 420 **The immune system and microbiota**

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

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

464

465 **Conclusions**

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

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790

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

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

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793

From Hasan et al. (2016) Animal

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795

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

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

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799

800 **Figure 1.** Relationship between litter size and duration of farrowing in 20 studies from 1992 to  
801 2018 (Oliviero et al., 2019).

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803

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

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809

810 **Figure 3.** Thermal image detecting skin temperature of newborn piglets receiving colostrum (right:  
811 36.2°C) or failing to reach the udder and ingest colostrum (left: 22.0°C). Image taken by Jena G.  
812 Alexopoulos (Alexopoulos et al., 2018).

813