Farrowing induction induces transient alterations in prolactin concentrations and colostrum composition in primiparous sows

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ABSTRACT: Hormonal changes involved in the farrowing process partly control the initiation of lactation. Inducing farrowing by injection of PG may alter the normal prepartum hormonal cascade. The aim of the study was to investigate the consequences of farrowing induction on colostrum yield and composition, as well as newborn piglet growth. Gilts were treated with 2 mg of alfaprostol on d 113 of gestation (induced farrowing, IF, n = 9) or were injected with 1 mL of a saline solution (natural farrowing, NF, n = 11). Colostrum production was estimated during 24 h, starting at the onset of parturition, based on piglet BW gains. Colostrum samples were collected during the 36 h after the onset of parturition. Blood samples were collected from sows as of d 112 of pregnancy until d 2 postpartum (d 0 being the day of parturition). Piglet blood samples were obtained at birth, on d 1, and on d 21. Litter size and litter weight at birth did not differ between groups (P > 0.10). Farrowing induction did not influence (P > 0.10) colostrum yield (3.96 ± 0.20 kg) or piglet BW gain during d 1 postpartum (116 ± 8 g). At the onset of farrowing (T0), lactose content in colostrum was greater in IF sows than in NF sows (P < 0.05), whereas colostrum ash and protein contents were less (P < 0.05) in IF sows. Concentrations of IgG in colostrum were similar in both groups of sows, whereas concentrations of IgA at T0 were less in IF than in NF sows (P < 0.01). Overall, endocrine changes in blood from d −2 until d 2 (cortisol, prolactin, progesterone, and estradiol-173) were not altered by farrowing induction (P > 0.10), but 1 h after the injection of alfaprostol, IF sows had greater circulating concentrations of prolactin (P < 0.01) and cortisol (P < 0.10) than NF sows. The greater concentration of lactose in colostrum from IF sows could be attributed to this transient increase in prolactin and cortisol. At birth, concentrations of white blood cells were less in piglets born from IF sows (P < 0.01). On d 1 and 21, piglets from IF sows had similar IgG concentrations in plasma to piglets from NF sows (P > 0.1). In conclusion, farrowing induction at 113 d of pregnancy induced transient hormonal changes in sows and alterations in colostrum composition, without significantly affecting colostrum yield. It also modified some hematological variables of piglets at birth.

Key words: colostrum yield, endocrinology, farrowing induction, immunoglobulin, lactogenesis, sow

INTRODUCTION

A large part of preweaning mortality in swine production occurs in early life (Tuchscherer et al., 2000). It can be attributed mainly to insufficient energy intake due to insufficient colostrum consumption by newborn piglets (Edwards, 2002; Le Dividich et al., 2005). Decreased colostrum intake also impairs the acquisition of maternal IgG for immune protection, thereby reducing subsequent resistance to a disease challenge. Colostrum intake by piglets depends both on their capacity to extract colostrum from mammary glands and on the capacity of sows to produce enough colostrum for the whole litter (Hoy et al., 1997). The factors affecting colostrum yield and composition are not fully known in sows (Farmer and Quesnel, 2009). Hormonal changes involved in the farrowing process partly control the initiation of lactation. Indeed, the decline in circulating progesterone concentrations before farrowing acts as a trigger for a succession of hormonal changes leading to farrowing and colostrum production (Martin...
et al., 1978; Liptrap, 1980). The extent to which the synchrony in these hormonal changes is important to ensure good colostrum production remains unknown. Farrowing induction by injection of a PGF2α analog was shown to modify and precipitate the normal prepartum hormonal cascade (Wettemann et al., 1977; Silver et al., 1983; Widowski et al., 1990). However, the impact of farrowing induction on lactogenesis is unclear. Farrowing induction was reported to reduce the risk of agalactia in sows (Einarsson et al., 1975) or to slightly reduce colostrum yield (Devillers et al., 2007). In the latter study, the impact of farrowing induction was confounded with a potential effect of gestation length. We hypothesized that farrowing induction might influence colostrum production by altering the normal prepaprtum hormonal cascade. The aim of the present study was to investigate the influence of farrowing induction on colostrum yield and composition, and consequences on passive immunity and growth of piglets.

**MATERIALS AND METHODS**

Sows and piglets were reared in compliance with French regulations for the humane care and use of animals in research.

**Sows and Piglets**

The experiment was conducted using the INRA experimental herd (Saint-Gilles, France). Twenty-two Landrace × Large White gilts were used in 4 replicates (3 replicates of 6 sows and 1 replicate of 4 sows). Gilts were inseminated with semen from Piétrain boars. During pregnancy, until the day of farrowing (d 0), gilts were fed (2.5 kg daily) a conventional gestation diet containing 13.3 MJ of DE/kg, 13.5% CP, and 0.5% lysine. After farrowing, sows received a conventional lactation diet containing 13.7 MJ of DE/kg, 17.4% CP, and 0.8% lysine. Sows were offered 2.5, 3.5, 4.5, and 5.5 kg of the lactation diet on d 1, 2, 3, and 4, respectively. The feed supply was then increased by 0.5 kg/d until ad libitum consumption on approximately d 9. Piglets had no access to creep feed throughout lactation. Water was freely available to sows and piglets throughout the experimental period.

At 101 ± 1 d of gestation, sows were moved from the gestation to the farrowing room. Sows were assigned to 1 of 2 experimental groups: induced farrowing (IF sows, n = 11) or natural farrowing (NF sows, n = 11). Parturition was induced by an intramuscular injection of 2 mg of alfaprostol, an analog of PGF2α (Alfabédyl, Ceva Santé Animale, Libourne, France), on d 113 of gestation. The IF sows were injected with 1 mL of a saline solution (154 mM NaCl). If colostrum could be easily extracted from the mammary gland of IF sows just before induction, the sow was not injected with alfaprostol but instead with the saline solution, and became an NF sow.

Sows were weighed just before being moved to the farrowing room (on d 101 of gestation), on d 112 of pregnancy, and on d 21 of lactation. On those same days, their backfat thickness was measured ultrasonically (Sonolayer SAL-32B, Toshiba, Tokyo, Japan) at the level of the 10th rib on each side, 65 mm from the midline. Piglets were weighed at 3, 7, 21, and 28 ± 1 d of age.

**Piglet Supervision During the First Postpartum Day**

Farrowing was attended as described previously (Foïsnet et al., 2010a). During farrowing, interventions were kept to a minimum. Births of the first and last piglets, respectively, were considered as the onset (T0) and the end of farrowing. Each piglet was weighed individually at birth and 24 h after the onset of farrowing (T24). Time between birth and the first suckling was recorded for each piglet. When this latency exceeded 40 min, the piglet was placed on the sow to suckle. No additional help or care was given to piglets before T24. Piglets weighing less than 0.7 kg at birth were euthanized immediately after birth because these piglets usually consume no or very little colostrum (H. Quesnel, unpublished data). Otherwise, the original litter was kept with the sow until T24. Beyond 24 h, litters were standardized to 12 piglets by cross-fostering within treatment groups.

**Surgery and Samplings**

At 101 ± 1 d of pregnancy, a catheter (2.16 mm o.d. and 1.02 mm i.d.; Silastic, Dow Corning, Midland, MI) was inserted through a collateral vein in the right external jugular vein. Surgery was performed under general anesthesia induced by an intravenous injection of propofol (Rapinovet, 30 mL/200 kg of BW, Schering Plough, Brussels, Belgium) after sedation with an intramuscular injection of ketamine (Imalgene, Merial, Lyon, France). Sows were fasted on the evening before surgery. After surgery, sows were moved to their farrowing crates (2 × 2.5 m) and were fed again.

**Blood Sampling in Sows.** Blood samples were collected every 6 h from d 112 of pregnancy to d 2 postpartum. Additional samples were collected just before and 1 h after the injection of alfaprostol or saline solution, and at the beginning of parturition, as well as 6 h later (T0 and T6, respectively). Blood samples (10 mL) were collected in heparinized tubes (37 IU/mL) kept on ice (5 mL) and in tubes containing no anticoagulant (5 mL). Heparinized samples were immediately centrifuged for 10 min at 2,600 × g at 4°C. Samples without anticoagulant were kept at ambient temperature for 4 h, stored overnight at 4°C, then centrifuged for 10 min at 2,600 × g at 4°C. Plasma and serum were stored at −20°C until analyses.
Colostrum and Milk Sampling. Colostrum was collected just after the birth of the first piglet, and then 6, 12, 24, and 36 h later (T0, T6, T12, T24, and T36, respectively). Colostrum and milk were collected from 6 to 8 teats located in the anterior, middle, and posterior parts of the udder. They were filtered through gauze and stored at −20°C. Thirty-five milliliters of colostrum were collected at T0 and T24, and 15 mL at T6, T12, and T36. From T6 and onward, 0.5 mL of colostrum were collected at T0 and T24, and 15 mL at T6, T12, and T36. From T6 and onward, 0.5 mL of colostrum were collected at T6, T12, and T36. From T6 and onward, 0.5 mL of colostrum were collected at T0 and T24, as described previously (Foisnet et al., 2010a). Briefly, N was determined by sample pyrolysis and direct determination of N2 using an automatic device (Leuco FP-428, Leuco Corporation, St. Joseph, MO); total lipids were measured according to the Gerber method (AOAC, 1990); and GE was measured using an adiabatic bomb calorimeter (C5000, IKA, Staufen, Germany). Lactose in colostrum was assayed at T0 and T24 using an enzymatic method (ref. 01766303, Lactose/d-galactose test combination, R-Biopharm). The Na and K contents were determined at T0, T6, T12, T24, and T36 with a Konelab 20i multichannel analyzer with ion selective electrodes after dilution with a solution for urine (reference 980303, Thermo Electron Corporation, Cergy Pontoise, France). The Na/K ratio in colostrum is inversely correlated with mammary epithelial integrity during lactation (Sørensen et al., 2001) and therefore was used as a second indicator of mammary epithelial integrity.

IgG and IgA in Colostrum. Concentrations of IgG and IgA were assayed in whole colostrum and milk by ELISA using a pig Ig ELISA Quantification Kit (references E100–104 and E100–102 for IgG and IgA, respectively, Bethyl Laboratories, Montgomery, TX), according to a method adapted and validated by I. Oswald (INRA, Toulouse, France). Concentrations of IgG were assayed at T0, T6, T12, T24, and T36 in colostrum samples diluted at 1/500,000. Concentrations of IgA were assayed at T0, T24, d 7, and d 21 in samples diluted at 1/50,000. Each dilution was measured in triplicate. For IgG and IgA, respectively, the intraassay CV were 2.9 and 3.1%, and the CV between ELISA plates were 8.3 and 6.3%.

Sow Plasma and Serum Assays

Steroids and Prolactin. All concentrations were determined in duplicate within single assays. Plasma concentrations of progesterone, estradiol-17β, and cortisol were measured by RIA using commercial kits (references IM1188, A21854, and IM1841, respectively; Beckman Coulter, Roissy CDG, France). The intraassay CV were 5.8, 6.0, and 5.6%, and the assay sensitivities were 0.1 ng/mL, 6 pg/mL, and 6.2 ng/mL for progesterone, estradiol-17β, and cortisol, respectively. Prolactin concentrations in serum were determined by a homologous double-antibody RIA (Robert et al., 1989). The prolactin intraassay CV was 4.8%, and average sensitivity was 1.8 ng/mL. The day of sampling was calculated in relation to the day of farrowing (d 0) a posteriori. Circulating concentrations were assayed from d −2 to 1 for steroids and from d −2 to 2 for prolactin.

Lactose. After deproteinization of plasma with perchloric acid and neutralization with potassium hydroxide, lactose was assayed using an enzymatic method (ref. 01766303, Lactose/d-galactose test combination, R-Biopharm, Darmstad, Germany). The assay sensitivity was 10.2 mg/L. Lactose concentrations were determined from d −3 until d 3 postpartum. Because lactose is exclusively synthesized by the mammary gland, plasma lactose concentration was used to evaluate the integrity of the mammary epithelium.

Colostrum Assays

Colostrum Composition. Crude contents in colostrum (GE, DM, ash, CP, and total lipids) were assayed at T0 and T24, as described previously (Foisnet et al., 2010a). Briefly, N was determined by sample pyrolysis and direct determination of N2 using an automatic device (Leuco FP-428, Leuco Corporation, St. Joseph, MO); total lipids were measured according to the Gerber method (AOAC, 1990); and GE was measured using an adiabatic bomb calorimeter (C5000, IKA, Staufen, Germany). Lactose in colostrum was assayed at T0 and T24 using an enzymatic method (ref. 01766303, Lactose/d-galactose test combination, R-Biopharm). The Na and K contents were determined at T0, T6, T12, T24, and T36 with a Konelab 20i multichannel analyzer with ion selective electrodes after dilution with a solution for urine (reference 980303, Thermo Electron Corporation, Cergy Pontoise, France). The Na/K ratio in colostrum is inversely correlated with mammary epithelial integrity during lactation (Sørensen et al., 2001) and therefore was used as a second indicator of mammary epithelial integrity.

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Piglet Blood Assays

IgG in Plasma. Immunoglobulin G was assayed in piglet plasma by using the pig IgG ELISA Quantification Kit (references E100–104, Bethyl Laboratories). Plasma was diluted at 1/180,000 for T24 samples and at 1/30,000 for d 21 samples. The intraassay CV was 2.1%, and the interassay CV was 10.1%.

Blood Composition. Hematocrit values and red blood cell and total white blood cell counts were analyzed using an automated hematology analyzer (Vet abc, Scil, Altorf, France). For each sample, a blood smear was prepared on a precleaned glass side (Menzel-Gläser, Braunschweig, Germany) for differential white blood cell counting. Blood smears were air-dried and stained using the May-Grünwald Giemsa staining.
method (Merck KGaA, Darmstadt, Germany), and 100 cells were counted under microscopic magnification.

**Estimation of Colostrum Production**

Colostrum intake by individual piglets between birth and T24 was estimated based on variation in piglet BW (Devillers et al., 2004) using the following equation: CI = −217.4 + (0.217 × t) + (1861019 × BW/t) + (54.8 − 1861019/t) × [(0.9985 − 3.7 × 10−4 × tFS) + (6.1 × 10−7 × tFS²)], where CI = colostrum intake (g); BW = BW at T24 (kg); t = time elapsed between the first and the second weighing (min), and tFS = the interval between birth and first suckling (min). Colostrum production by the sow during the 24 h after the onset of parturition was calculated as the sum of intakes by each piglet of the litter.

**Statistical Analyses**

Two IF sows were excluded from the experiment: 1 sow because she farrowed only 8 h after the injection of alfaprostol, suggesting that farrowing was not experimentally induced, and another sow because colostrum yield could not be estimated. The latter sow was aggressive toward her piglets and spent a lot of time standing.

Zootechnical data other than mortality rate were analyzed with ANOVA using the GLM procedure (SAS Inst. Inc., Cary, NC). Sow and litter performances were analyzed with a model which included induction as the main effect: Yij = µ + Ii + Sj + Qk + (I × Q)ik + eijk, where Yij = dependent variable; µ = overall mean; Ii = induction (i = yes, no); Sj = sow nested within induction; Qk = quartile of birth order (k = 1 to 4); (I × Q)ik = interaction between induction and quartile of birth order; eijk = residual error. The effect of induction was tested against the experimental error term (sow nested within induction).

Mortality rates were analyzed using the GENMOD procedure (stillbirth rate = number of stillborn piglets/number of piglets; mortality rate from birth to 24 h = number of piglets that died between birth and T24/number of piglets born alive).

Hormonal and biochemical data were analyzed using the REPEATED statements in the MIXED procedure (Littell et al., 1998; SAS Inst. Inc.): Yijk = µ + Ii + Tj + (I × T)ij + Sj + eijk, where Yijk = dependent variable; µ = overall mean; Ii = induction (i = yes, no); Tj = sampling time; (I × T)ij = interaction between induction and sampling time; Sj = sow nested within treatment; eijk = residual error. When the effect of sampling time was significant, means were separated by F-protected LSD.

**RESULTS**

**Sow Characteristics**

Sow BW and backfat thickness on d 112 of pregnancy and on d 21 of lactation were similar (P > 0.10) in the 2 groups of sows (Table 1). Time elapsed between injections of PGF2α analog or saline and the onset of farrowing, gestation length, and farrowing duration did not differ significantly (P > 0.10) between groups.

**Piglet and Litter Characteristics and Litter Performance During Early Lactation**

Characteristics of the litter nursed during the first day postpartum, in terms of piglet number, litter

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**Table 1.** Sow BW and backfat thickness, and duration of gestation and farrowing for each treatment group (mean ± SEM)1

<table>
<thead>
<tr>
<th>Item</th>
<th>NF</th>
<th>IF</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of sows</td>
<td>11</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>BW on d 112 of gestation, kg</td>
<td>205 ± 2</td>
<td>201 ± 4</td>
<td>0.313</td>
</tr>
<tr>
<td>Backfat thickness on d 112 of gestation, mm</td>
<td>16.9 ± 0.7</td>
<td>18.0 ± 0.8</td>
<td>0.294</td>
</tr>
<tr>
<td>Gestation length, d</td>
<td>114.2 ± 0.3</td>
<td>114.0 ± 0.0</td>
<td>0.589</td>
</tr>
<tr>
<td>Farrowing duration, min</td>
<td>162 ± 13</td>
<td>176 ± 37</td>
<td>0.707</td>
</tr>
<tr>
<td>Time elapsed between injection of PGF2α analog or saline and the onset of farrowing, h</td>
<td>28 ± 7</td>
<td>24 ± 1</td>
<td>0.574</td>
</tr>
<tr>
<td>BW on d 21 of lactation, kg</td>
<td>180 ± 4</td>
<td>177 ± 3</td>
<td>0.649</td>
</tr>
<tr>
<td>Backfat thickness on d 21 of lactation, mm</td>
<td>13.2 ± 0.6</td>
<td>13.1 ± 0.5</td>
<td>0.833</td>
</tr>
</tbody>
</table>

1NF = sows with natural farrowing; IF = sows with induced farrowing.
weight, and mean piglet BW, were similar in NF and IF groups \( (P > 0.10; \text{Table 2}) \). Mean piglet BW gain between birth and T24 was not affected by treatment \( (P > 0.10) \) and averaged 124 ± 4 g. The time elapsed between birth and the first suckling by newborn piglets tended to be greater in IF than in NF litters \( (P = 0.06) \). Litter weight gain and estimated colostrum yield for the first 24 h postpartum were not influenced by farrowing induction \( (P > 0.10) \). Rate of stillbirth and rate of mortality from birth to T24 averaged 1.2 ± 0.1% and 5.6 ± 1.5%, respectively, and were similar in the 2 groups of sows \( (P > 0.10) \).

### Colostrum Composition

At T0, the lactose content of colostrum was less in NF than in IF sows \( (P < 0.05; \text{Table 3}) \), whereas ash and protein contents were greater \( (P < 0.05) \) in NF sows. Concentrations of IgG in colostrum were not influenced by treatment \( (P > 0.10; \text{Figure 1}) \), whereas those of IgA were less in IF than in NF sows at T0 \( (P < 0.01; \text{Figure 2}) \).  

<table>
<thead>
<tr>
<th>Item</th>
<th>NF</th>
<th>IF</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litter size(^2)</td>
<td>11.4 ± 0.6</td>
<td>12.2 ± 1.3</td>
<td>0.579</td>
</tr>
<tr>
<td>Litter birth weight,(^2) kg</td>
<td>15.3 ± 0.6</td>
<td>14.7 ± 1.4</td>
<td>0.703</td>
</tr>
<tr>
<td>Mean piglet BW at birth,(^2) kg</td>
<td>1.34 ± 0.04</td>
<td>1.23 ± 0.05</td>
<td>0.112</td>
</tr>
<tr>
<td>Mean piglet BW gain between birth and T24, g</td>
<td>135 ± 6</td>
<td>112 ± 6</td>
<td>0.361</td>
</tr>
<tr>
<td>Birth to suckling interval, min</td>
<td>27 ± 1</td>
<td>32 ± 2</td>
<td>0.059</td>
</tr>
<tr>
<td>Colostrum intake by individual piglets, g</td>
<td>357 ± 18</td>
<td>331 ± 19</td>
<td>0.320</td>
</tr>
<tr>
<td>Litter weight gain between T0 and T24,(^3,4) kg</td>
<td>1.49 ± 0.15</td>
<td>1.35 ± 0.11</td>
<td>0.309</td>
</tr>
<tr>
<td>Colostrum production between T0 and T24,(^4) kg</td>
<td>4.06 ± 0.25</td>
<td>3.83 ± 0.31</td>
<td>0.108</td>
</tr>
</tbody>
</table>

\(^1\)NF = sows with natural farrowing; IF = sows with induced farrowing.
\(^2\)Piglets nursed during the 24 h after the onset of farrowing.
\(^3\)T0: onset of farrowing = birth of the first piglet, T24: 24 h after the onset of farrowing.
\(^4\)Litter size was introduced as a covariate.

### Steroid and Prolactin Concentrations Around Farrowing and at the Injection of PGF\(_{2 \alpha}\), Analog

From d −2 to 2, there was no interaction between treatment and sampling time for profiles of steroid and prolactin concentrations \( (P > 0.10) \). There was no effect of treatment \( (P > 0.10) \) on circulating concentrations of progesterone, estradiol-17β, cortisol, or prolactin (Figures 3 and 4).

Progesterone, prolactin, and cortisol response to the injection of alfaprostol are shown in Figure 5. Plasma concentrations of progesterone were similar in IF and NF sows before and after farrowing induction \( (P > 0.10; \text{Figure 5A}) \). Concentrations of prolactin and cortisol did not differ between NF and IF sows just before farrowing induction, but 1 h after the induction, IF sows had greater concentrations of prolactin \( (P < 0.01) \) and cortisol \( (P < 0.05) \).
Figure 2. Concentrations of IgA in colostrum and milk for each treatment group (mean ± SEM). On d 0 and 1, samples were collected at the onset of farrowing and 24 h later, respectively. NF = sows with natural farrowing; IF = sows with induced farrowing. Sampling times without a common letter (a,b) differ ($P < 0.05$). Effect of farrowing induction: **$P < 0.01$.

Figure 3. Plasma concentrations of progesterone (A), estradiol-17β (B), and serum concentration of prolactin (C) around farrowing for each treatment group (mean ± SEM). NF = sows with natural farrowing; IF = sows with induced farrowing.

Figure 4. Plasma concentrations of cortisol around farrowing for each treatment group (mean ± SEM). NF = sows with natural farrowing; IF = sows with induced farrowing.

Figure 5. Concentrations of progesterone (A), prolactin (B), and cortisol (C) just before the injection of PGF$_2$α analog or saline and 1 h after injection for each treatment group (mean ± SEM). NF = sows with natural farrowing; IF = sows with induced farrowing. Effect of farrowing induction: †$P < 0.10$, **$P < 0.01$. 

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and tended to have greater concentrations of cortisol ($P < 0.1$) than NF sows (Figures 5B and 5C).

**Indicators of Integrity of Mammary Epithelium**

**Lactose in Plasma.** Before 12 h prepartum, plasma concentrations of lactose were below assay sensitivity. Concentrations of lactose averaged 10.9 ± 0.9 mg/L 12 h before the onset of farrowing (Figure 6A), increased ($P < 0.001$) to reach maximal values averaging 39.8 ± 3.4 mg/L at T6, and then decreased and remained decreased from 12 to 48 h postpartum compared with T6. Plasma concentrations of lactose were similar in NF and IF sows between 12 h prepartum and 48 h postpartum ($P > 0.10$).

**Na/K Ratio in Colostrum.** The Na/K ratio was not affected by treatment ($P > 0.10$; Figure 6B). The Na/K ratio decreased at T12 and remained decreased from T12 until T36 compared with T0 and T6.

**Blood Characteristics of Piglets**

**Blood Composition of Piglets at Birth.** Hematocrit, hemoglobin, and total red blood cell concentrations in piglets at birth were similar in the 2 groups of piglets ($P > 0.10$; Table 4). Concentrations of white blood cells were less in piglets from IF sows ($P < 0.05$). Lymphocyte concentrations were not affected by treatment ($P > 0.10$), but neutrophil concentrations were less in piglets from IF sows than piglets from NF sows ($P = 0.01$).
Plasma IgG. Plasma IgG concentrations at T24 and on d 21 of lactation were not influenced by treatment ($P > 0.10$; Figure 7). Across treatments, piglets born in the third and last quartiles of the farrowing process had decreased IgG concentrations at T24 compared with piglets born in the first quartile ($P < 0.05$). On d 21, piglets born in the third quartile had decreased IgG concentrations compared with piglets born in the first quartile ($P < 0.05$).

Performances During Lactation

After litter size standardization on d 1, ADG of piglets from d 1 until d 21 was greater in NF than in IF litters ($P < 0.05$). On d 21, mean piglet BW was greater in NF than in IF litters ($P < 0.05$; Table 5). No treatment differences were observed in milk composition (DM, ash, proteins, lactose, or GE contents) on d 7 or 21 ($P > 0.10$; data not shown).

Table 4. Hematological variables in piglet blood immediately after birth for each treatment group (mean ± SEM)$^{1}$

<table>
<thead>
<tr>
<th>Item</th>
<th>NF</th>
<th>IF</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of piglets</td>
<td>29</td>
<td>33</td>
<td>0.652</td>
</tr>
<tr>
<td>Hematocrit, %</td>
<td>34.3 ± 0.6</td>
<td>33.7 ± 0.6</td>
<td>0.599</td>
</tr>
<tr>
<td>Hemoglobin, g/100 mL</td>
<td>10.3 ± 0.2</td>
<td>9.8 ± 0.2</td>
<td>0.946</td>
</tr>
<tr>
<td>Total red blood cell count, $\times 10^6$ cells/µL</td>
<td>5.27 ± 0.11</td>
<td>5.18 ± 0.11</td>
<td>0.037</td>
</tr>
<tr>
<td>Total white blood cell count, $\times 10^9$ cells/µL</td>
<td>5.53 ± 0.31</td>
<td>4.41 ± 0.25</td>
<td>0.417</td>
</tr>
<tr>
<td>Lymphocyte count, $\times 10^3$ cells/µL</td>
<td>1.43 ± 0.16</td>
<td>1.31 ± 0.15</td>
<td>0.141</td>
</tr>
<tr>
<td>Neutrophil count, $\times 10^3$ cells/µL</td>
<td>4.00 ± 0.32</td>
<td>2.96 ± 0.25</td>
<td>0.014</td>
</tr>
</tbody>
</table>

$^{1}$NF = sows with natural farrowing; IF = sows with induced farrowing.

Figure 7. Effect of birth order on plasma concentrations of IgG in piglets 24 h after the birth of the first piglet (A) and on d 21 (B) for each treatment group (means ± SEM). NF = sows with natural farrowing; IF = sows with induced farrowing. Across treatment, means without a common letter (a–c) differ ($P < 0.05$).
concentrations 1 h after the injection of PGF2α analog. 
panied by transient increases in prolactin and cortisol 
induction of farrowing in the current study was accom-
the timing of treatment, given at 109 to 111 d of gesta-
Discrepancies between experiments could be related to 
during spontaneous luteolysis (Foisnet et al., 2010a,b).
one decline in the present experiment, which contrasted 
Alfaprostol injection did not accelerate the progester-
one concentrations was reported in response to 
the injection of PGF2α or its analog cloprostenol at the 
end of gestation (Wettemann et al., 1977; Silver et al., 
These previous reports showed that progester-
one concentrations decreased by one-half within 4 h 
after cloprostenol injection or 12 h after PGF2α injec-
tion, whereas such a decrease required at least 36 h 
during spontaneous luteolysis (Foisnet et al., 2010a,b).
Discrepancies between experiments could be related to 
the timing of treatment, given at 109 to 111 d of gesta-
tion in the study from Silver et al. (1983). Nevertheless, 
induction of farrowing in the current study was accom-
panied by transient increases in prolactin and cortisol 
concentrations 1 h after the injection of PGF2α analog. 
Similar changes were reported previously a few hours 
after the injection of PGF2α or cloprostenol (Silver et al., 
1983; Widowski et al., 1990). These results sug-
gest that PGF2α and its analogs act directly on the 
anterior pituitary gland to stimulate prolactin release 
(Gautvik and Kriz, 1976) and probably also act on the 
adrenal cortex, because most PG increase adrenal ste-
roidogenesis and steroid release (Liggins et al., 1982). 
The greater concentrations of lactose in colostrum of 
IF sows at the onset of farrowing could be attributed 
to this transient increase in prolactin and cortisol con-
centrations. The activity of the lactose synthase, an 
enzymatic complex including α-lactalbumin and galac-
tosyltransferase, markedly increases during the final 
stage of lactogenesis in sows (Dodd et al., 1994). The 
expression of α-lactalbumin is upregulated by prolac-
tin (Rosen et al., 1999; Tucker, 2000), and the expres-

DISCUSSION

To avoid confounding effects of parturition induction 
and gestation length, parturition was induced around 
36 h before the expected parturition, based on the 
average gestation length (115 d) currently observed in 
our herd with primiparous sows. In the current project, 
sows farrowed 24 h after the injection of PGF2α analog. 
Progesterone profiles indicate that natural luteolysis 
may have already started in some IF sows when the 
PGF2α analog was injected, yet colostrum could not be 
easily obtained from the mammary gland at that time.

Alfaprostol injection did not accelerate the progester-
one decline that PGF2α and its analogs act directly on the 
epithelium. The absence of maturation of the mammary 
epithelium was similar in IF and NF sows, as illustrated 
by previous reports showing a greater dilution of colostrum 
when compared with NF sows. The effect of PGF2α 
analog injection on the composition of mammary 
secretions was only transitory because on d 1 and 
7, milk composition was not affected by farrowing in-
duction.

Besides its transient effects on prolactin and cortisol 
concentrations, farrowing induction did not modify 
global endocrine changes around the time of farrowing. 
In accordance, the permeability of the mammary ep-
ithelium was similar in IF and NF sows, as illustrated 
by similar profiles of Na/K ratio in colostrum and lac-
tose in maternal plasma. Sealing of the tight junctions 
between neighboring mammary epithelial cells is nec-

sion of the prolactin receptor in mammary epithelial 
cells is upregulated by cortisol (Delouis et al., 1980). 
Given that lactose is an important osmotic component 
in maternal plasma. Sealing of the tight junctions 
between neighboring mammary epithelial cells is nec-

T able 5. Piglet performance during lactation for each treatment group (mean ± SEM)1

<table>
<thead>
<tr>
<th>Item</th>
<th>NF</th>
<th>IF</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of sows</td>
<td>10</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Litter size during lactation2</td>
<td>11.6 ± 0.2</td>
<td>11.3 ± 0.3</td>
<td>0.309</td>
</tr>
<tr>
<td>Litter weight on d 1, kg</td>
<td>17.7 ± 0.7</td>
<td>15.8 ± 0.6</td>
<td>0.046</td>
</tr>
<tr>
<td>Mean piglet BW on d 1, kg</td>
<td>1.47 ± 0.06</td>
<td>1.36 ± 0.05</td>
<td>0.196</td>
</tr>
<tr>
<td>Mean piglet BW on d 21, kg</td>
<td>6.67 ± 0.15</td>
<td>6.05 ± 0.17</td>
<td>0.014</td>
</tr>
<tr>
<td>ADG from d 1 to 21, g</td>
<td>263 ± 6</td>
<td>239 ± 7</td>
<td>0.018</td>
</tr>
</tbody>
</table>

1NF = sows with natural farrowing; IF = sows with induced farrowing.
2Average number of piglets nursed between d 1 and 21.
viously reported that induction of farrowing with natural PGF$_2\alpha$ reduced fetal oxygenation only 15 min after the injection and that this effect was transient. On the other hand, premature induction of farrowing (on d 109 to 111) decreased the viability and the vitality of piglets because piglets did not have the ability to suckle adequately (Silver et al., 1983). But this was not the case in the present study because farrowing induction was performed on d 113 of pregnancy; thus, piglets from IF sows had the same gestational age and, hypothetically, the same maturity at birth as piglets from NF sows. This greater birth-to-suckling interval could be attributed to the lighter birth weight of piglets from IF sows, although this difference was not significant.

Farrowing induction had no impact on concentrations of IgG in colostrum, but transiently reduced those of IgA. The mechanisms mediating the uptake of IgG from the blood to the mammary glands are not well known in the sow. Although passive diffusion between mammary epithelial cells cannot be excluded, active transport is likely to occur because IgG concentrations are 5 to 7 times greater in colostrum than in blood at the onset of farrowing (Huang et al., 1992; Foisnet et al., 2010a). Such transport could be mediated by an Fc-specific receptor located on the basolateral membrane of mammary epithelial cells, known as the neonatal Fc receptor (FcRn; Schnulle and Hurley, 2003). In cattle, the decrease in progesterone/estrogen ratio was suggested to stimulate the initiation of FcRn activity in the mammary gland (Barrington et al., 2001); on the other hand, prolactin decreased the expression of the FcRn (Barrington et al., 1999). The fact that farrowing induction did not alter endocrine changes in the peripartum period could explain the lack of difference in colostral IgG contents between the 2 experimental groups. These findings are in agreement with previous reports where induction of farrowing between d 110 and 113 of pregnancy did not decrease IgG contents in colostrum of sows (Jackson et al., 1995; Walkiewicz et al., 2006). Unlike IgG, IgA in colostrum only partly originates from maternal serum but largely originates from immune cells that migrate from the gut and upper respiratory tract to the mammary gland (Salmon et al., 2009). Then IgA is translocated into colostrum and milk by the polymeric receptor (pIgR), whose expression is upregulated by prolactin and glucocorticoids in rabbits and ruminants (Rosato et al., 1995; Rincheval-Arnold et al., 2002). Concentrations of IgA in colostrum could depend on both the expression of pIgR and cell trafficking (Salmon et al., 2009). The different impacts of farrowing induction on colostrum IgG and IgA concentrations might be related to the different pathways controlling IgG and IgA transfer to mammary secretions.

An increase in both fetal and maternal concentrations of cortisol was reported when farrowing was induced by PGF$_2\alpha$, or cloprostenol (Silver et al., 1983; Randall, 1990). Glucocorticoids have a wide range of maturational effects in utero (Fowden et al., 1998). They induce both structural and functional changes in a variety of fetal tissues, such as the lungs, gut, and liver, and activate many of the biochemical processes that prepare the fetus for extrauterine life. In cesarean-delivered piglets, treatment with metyrapone (a cortisol inhibitor) was associated with reduced plasma concentrations of IgG on d 3 postpartum (Sangild et al., 1993). Furthermore, glucocorticoids or endogenous PGF$_2\alpha$, are known to induce immunomodulating effects, such as enhancing leukocyte concentrations in blood (Kavelaars et al., 1996; de Menezes et al., 2005). In the current study, the blood composition of piglets just after birth was affected by farrowing induction. Piglets from IF sows had decreased white blood cells concentrations and decreased neutrophil concentrations compared with piglets from NF sows. However, these effects of farrowing induction on hematological data are not consistent with the positive effect of glucocorticoids or PGF$_2\alpha$ on leukocyte concentrations generally reported in the literature (Kavelaars et al., 1996; de Menezes et al., 2005).

Concentrations of IgG in the plasma of piglets on d 1 and 21 were not influenced by treatment, suggesting that the capacity of IgG absorption by piglets was similar in both groups. In agreement with previous results (de Passillé et al., 1988; Le Dивидич et al., 2004), an effect of birth order was observed on piglet IgG concentrations. Indeed, at 24 h, piglets born in the third and fourth quartiles of the farrowing process had less IgG in their plasma than piglets born in the first quartile. It was suggested earlier that piglets born in the second part of farrowing have access to colostrum that may contain less IgG than the colostrum available just after the onset of farrowing (de Passillé et al., 1988; Le Dивидич et al., 2004). It is interesting to note, however, that on d 21, the effect of birth order was less marked.

Between d 1 and 21 of lactation, ADG of piglets from IF sows was less than that of piglets from NF sows. This slower growth rate could be due to the fact that IF litters were lighter on d 1 after standardization of litter size. It is well known that total milk production increases with litter size or litter weight, which reflects the capacity of stimulation of the mammary gland by piglets (Boyce et al., 1997; King, 2000). Alternatively, the slower growth rate of piglets from IF sows could be due to a decreased colostral supply of proteins. Because colostrum from IF sows seemed to be more diluted than colostrum from NF sows, it is possible that growth factors were also present at decreased concentrations. Whether a decreased supply of growth factors could be involved in the slower piglet growth rate is unknown. Nevertheless, given the present findings, it is important to investigate the influence of farrowing induction on piglet performance until weaning on a larger number of animals.

In conclusion, farrowing induction on d 113 of gestation induced a transient increase in prolactin and corti-
sol concentrations 24 h before parturition, which might be responsible for the transient alterations in colostrum composition at the onset of farrowing. With regard to newborn piglets, farrowing induction altered neither their BW gain during the first day of postnatal life nor their circulating concentrations of IgG, but modified their hematological variables, such as total white blood cell count. Whether these alterations in colostrum composition were involved in the slower growth rate of piglets during lactation needs to be further investigated.

LITERATURE CITED


