Individual physical characteristics of neonatal piglets affect preweaning survival of piglets born in a noncrated system

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ABSTRACT: The aim of this study was to investigate the effects of individual physical characteristics on preweaning survival and growth of piglets born in a noncrate system. Data were collected from 3,402 neonatal piglets from 203 Landrace × Yorkshire sows housed in noncrate pens in a commercial Danish sow herd. Piglets were categorized into groups according to their survivability: surviving to weaning (SURV), stillborn (STILL), or dead between birth and weaning (DBW), which was subdivided into dead d 0 to 1 after farrowing (DEAD1) or dead d 2 to 26 after farrowing (DEAD26). Linear models were used to determine which physical characteristics affected survivability and growth of piglets. Results showed that characteristics related to the individual piglets had a greater degree of explanatory power in relation to survival than variables related to the sow. Survival of piglets increased if piglets were females (P < 0.001), had a greater body mass index (P < 0.001), and were born to sows of parity 3 or more (P = 0.017). Piglets with a greater birth weight were more likely to survive (P < 0.001), but birth weight was inferior to body mass index in explaining differences between SURV and DBW. Piglets that died 2 to 26 d after birth had a lower birth weight (P < 0.001), were born to sows of parity 1 or 2 (P = 0.014), and were born after a shorter gestation (P = 0.011) compared with SURV. Piglets that died on d 0 to 1 after birth had a lower body mass index (P < 0.001), displayed a greater degree of growth restriction (P = 0.004), and were born in large litters (P = 0.005). The gender of the piglets affected survivability at both d 0 to 1 (P < 0.001) and d 2 to 26 (P < 0.001). Piglets in DEAD1 differed from STILL by having a shorter crown to rump length (P < 0.001), a birth weight that deviated more from the mean weight of the litter (P = 0.001), and being more likely to be born before d 116 of gestation (P = 0.008). The only physical characteristic that was important for growth performance in the suckling period was birth weight (P < 0.001), yet using only birth weight as an indicator for survivability was too simplistic. The results of this study emphasize that individual characteristics of neonatal piglets could serve as indicators of survivability of piglets born in noncrate systems; however, the results suggest that the importance of characteristics differed in different periods of the preweaning period.

Key words: body mass index, piglet, physical characteristics, ponderal index, preweaning survival


INTRODUCTION

The implementation of noncrate farrowing systems may be challenged by increased piglet mortality (Blackshaw et al., 1994; Marchant et al., 2000; Jarvis et al., 2005). Studies have shown that characteristics related to the behavior and physiology of neonatal piglets are indicative of survival (De Roth and Downie, 1976;
Tuchscherer et al., 2000), but these characteristics can only be obtained under experimental conditions. To be of use under commercial conditions, characteristics of survivability should be related to the physical appearance of the piglet.

The relationship between birth weight and survivability is well established (van der Lende and de Jager, 1991; Roehe and Kalm, 2000), but recent studies suggest that other indicators of body conformation, such as body mass index and ponderal index, might also be important indicators of survivability (Baxter et al., 2008, 2009). In addition, morphological traits can indicate intrauterine growth restriction, which decreases survivability (Chevaux et al., 2010). It is unknown how these characteristics affect growth performance of suckling piglets. This issue should therefore be elucidated to establish whether physical characteristics can serve as indicators of growth performance as well as survivability. The importance of survival indicators may differ across production systems (Baxter et al., 2008, 2009), suggesting that before introducing noncrate farrowing systems, piglets at risk of dying in such systems should be identified.

The aim of this study was to investigate if individual physical characteristics of neonatal piglets born in an indoor, noncrate system could be used as indicators of survivability and growth performance of suckling piglets. Thus, the hypothesis that birth weight, relative birth weight in litter, body length, body mass index, ponderal index, degree of growth restriction, and gender affected survivability and growth performance of the individual piglet was tested in this experiment.

**MATERIALS AND METHODS**

The study was conducted in accordance with the guidelines of Danish Ministry of Justice Act 382 (June 10, 1987) and Acts 333 (May 19, 1990), 726 (September 9, 1993), and 1016 (December 12, 2001), with respect to animal experimentation and care of animals under study. The study was conducted in a 1,200-sow (Danish Landrace × Danish Yorkshire) Danish piggery (Gl. Refning, Sørvad, Denmark), where farrowings took place in batches of 110 to 130 sows every 3 wk. The study was conducted in the spring, and data were recorded from 2 consecutive batches from first farrowing until weaning.

**Animals and Management Routines**

This study involved 3,402 crossbred piglets from 203 litters. The sows in the study were of parity 1 to 6 (mean ± SD: 2.9 ± 1.1), and all sows were artificially inseminated with production semen from Duroc boars (Hatting KS, Horsens, Denmark). During the gestation period, females were fed a mash diet based on wheat, barley, and soybean meal. This gestation diet contained 8.0 MJ potential physiological energy/kg feed (Boisen, 2001) and 5.81 g standardized ileal digestible Lys/kg feed. During gestation, females were fed once a day according to parity and body condition, with fat, medium, and thin sows and gilts receiving 2.4, 2.9, 3.9, and 2.3 kg feed/d from d 0 to 28 of gestation, respectively. Between d 29 and 84 of gestation fat, medium, and thin sows and gilts were fed 1.9, 2.5, 3.6, and 2.9 kg feed/d, respectively, and from d 85 until placement in the farrowing pens, fat, medium, and thin sows and gilts received 3.4, 3.4, 3.9, and 3.2 kg feed/d, respectively.

A handful of straw was provided once daily from placement of sows in the farrowing pens to weaning. During the days of farrowing, staff performed regular rounds through the farrowing unit to inspect sows that farrowed. Rounds were conducted every 30 to 60 min from 0500 to 1600 h and from 2100 to 2300 h. Obstetric aid was performed when deemed necessary. Sows were fed a mash lactation diet in agreement with Danish recommendations (Jørgensen and Tybirk, 2010) based on barley, wheat, and soybean meal with 8.4 MJ potential physiological energy/kg feed (Boisen, 2001) and 7.47 g standardized ileal digestible Lys/kg feed. Before farrowing, sows were fed 2 times a day (0700 and 1400 h) and received a total of 3.8 (gilts) or 4.4 kg (sows) feed/d. Around farrowing, the daily feed ration was reduced to 2.2 kg feed/d, but after farrowing, the ration was increased to 3.8 (gilts) and 4.4 kg (sows) feed/d on d 2. Then the feed ration was increased by 1.09 kg feed/d for 3 d and then by 0.5 kg feed/d for 2 d to an allowance of 8.7 kg feed/d on d 7 after farrowing. Thereafter the ration was increased by 3% (gilts) or 6% (sows) every 2 d if the sows emptied the troughs. After farrowing, the number of feedings was furthermore increased to 4 times a day (0700, 1100, 1400, and 2100 h), and piglets were closed inside the creep area during the first 2 feedings after farrowing. Sows had ad libitum access to water via drinking nipples throughout the period from insertion to weaning. The first 2 d after parturition, rectal temperatures of the sows were measured at the 1100 h feeding, and sows with elevated rectal temperatures (>38°C) were treated with antibiotics (Duoprim, Intervet Danmark, Ballerup, Denmark).

Litters were equalized by cross-fostering piglets born within the same 12 to 24 h when it was ensured that all piglets had consumed colostrum. Gilt litters were equalized to 15 piglets and litters of sows of second parity or, later, were equalized to 14 piglets. On the first day after parturition, a piece of Band-Aid was fixed on the belly of all piglets when their cords were dry to reduce potential navel hernia, and first-parity litters had the tips of their teeth ground. Tail docking, injection of iron (Solofer, Vitfoss, Grästen, Denmark), and surgical
castration were performed on d 4. Piglets were weaned at 4 wk. Piglets that were traumatized or diseased or for other reasons deemed unable to survive to weaning were euthanized by blunt-force trauma. Besides the registrations made in the study, all animals were managed according to the general routines of the herd.

**Housing**

Sows were housed in groups during mating and gestation. In the mating unit, sows were housed in a deep bedded system with 6 pens where they were housed in groups of 35 to 40 sows/pen. The gestation unit consisted of 36 identical pens with solid and slatted flooring, and sows were housed in groups of 30 in each pen. Seven days before expected farrowing, the sows were placed in individual farrowing pens. The farrowing unit consisted of 4 identical sections, each with 84 pens, that were diffuse ventilated with a room temperature of 18°C to 21°C. In the farrowing rooms artificial light was on from 0700 to 1600 h, and when the sows farrowed it was also on from 0500 to 0700 h and from 2100 to 2300 h.

The individual farrowing pens measured 2.7 × 1.7 m and had slatted metal floors in the center of the pen and slatted plastic floors along the solid pen separations (Fig. 1). The pen separations were 0.9 m high, and there were farrowing rails on 3 sides of the pen. The creep entrance was fitted with 4 horizontal rails to a height of 0.9 m and with 6 “fingers” at the bottom rail to prevent the sow from accessing the creep area. The creep area could be accessed from the inspection aisle and had an area of 0.9 m². An adjustable roof covered 0.5 m² of the creep area, and a rubber mat was placed on the floor in this area, whereas the floor outside the covered area was slatted. In the first days after parturition, sawdust was spread in the creep area as bedding material, and in the first week a 150-W heat lamp was provided in the covered part of the creep area. Generally, bedding material was present in the creep area for the first week after parturition.

**Recordings**

The day of parturition was denoted as d 0. On the day of parturition, before litter equalization, all piglets were closed inside the creep area and individually marked with a small ear tag (Tip tag, ALLFLEX danmark aps, Lemvig, Denmark). The gender of the piglet was noted, piglets were weighed individually, and the crown to rump length was measured (the supine length of the piglet from the crown of the head to the base of the tail). The degree of intrauterine growth restriction (IUGR) was graded visually as either normal, light IUGR, or IUGR on the basis of the shape of the head. These definitions were based on the head morphology of the piglets (Fig. 2) and 3 criteria that characterize growth-restricted piglets (Chevaux et al., 2010): 1) steep, dolphin-like forehead, 2) bulging eyes, and 3) wrinkles perpendicular to the mouth. If all 3 criteria applied to a piglet, it was defined as IUGR (score of 3); if 1 or 2 characteristics applied, it was defined as light IUGR (score of 2), and if none of the 3 criteria applied, it was deemed normal (score of 1).

When piglets were moved between sows, both during and after litter equalization, the date of movement and the sow it was moved to were noted. Piglets were weighed individually before weaning on d 23 to 28 postpartum (mean ± SD: 25.5 ± 1.23 d).

Treatment with antibiotics was noted for each individual piglet as well as cause of death. Diseased piglets were treated with Clamoxyl Prolugmatium (Orion Pharma Animal Health, Nivå, Denmark) for diarrhea and with Streptipen prokain (Ceva Animal Health A/S, Vejle, Denmark) and Florkem (Ceva Animal Health A/S, Vejle, Denmark) for arthritis or other hoof/leg injuries.

**Postmortem Examination**

All piglets that died before d 26 were weighed and stored at −20°C until they were subjected to a postmortem examination to confirm the cause of death. Stillbirth was determined by inflation of the lung tissue. If the lung tissue would not float in water, the piglet
was categorized stillborn. A piglet was categorized as crushed if there were obvious signs of trauma, subcutaneous edema, or both in any part of the body. Piglets that were deemed unable to survive on their own and subsequently euthanized by the staff were classified as weak along with piglets that showed no signs of crushing but had not received colostrum. Piglets that did not display any signs of crushing and at the same time were emaciated and had an empty stomach, along with very little or no contents in the intestines, were classified as dead due to starvation. Piglets that died from disease, piglets that were euthanized by the staff because of disease or hernias, and piglets that could not be accurately classified at the postmortem examination were categorized as dead from other causes.

### Calculations and Statistical Analyses

Indices of body conformation were calculated on the basis of measurements of the weight and the length of the individual piglets. The body mass index of a piglet was calculated as

\[ \text{body mass index} = \frac{\text{birth weight (kg)}}{\text{(crown to rump length (m))}^2} \]

The ponderal index of a piglet was calculated as

\[ \text{ponderal index} = \frac{\text{birth weight (kg)}}{\text{(crown to rump length (m))}^3} \]

The relative birth weight of a piglet in a litter was calculated from the mean birth weight of the litter and the birth weight of the individual piglet as

\[ \text{relative birth weight} = \frac{(\text{piglet birth weight} - \text{mean birth weight of litter})}{\text{mean birth weight of litter}} \times 100 \]

All analyses were performed with piglet as the observational unit. Piglets were categorized into 3 groups: stillborn piglets (STILL), live-born piglets that died between birth and weaning (DBW), and piglets surviving to weaning (SURV). The group of DBW was subdivided into piglets that died on d 0 to 1 (DEAD1) and piglets that died between d 2 and 26 (DEAD26), as preliminary analyses showed differences in characteristics of piglets that died shortly after birth and those that died later during the preweaning period. Six models were used to analyze differences in physical characteristics of groups (Table 1). Differences between groups were analyzed using linear models (SAS Inst. Inc., Cary, NC), with groups as the multinomially (model 1) or binomially (models 2, 3, 4, 5, and 6) distributed response variables. The 6 models were found using a forward selection process. The combinations of variables that best explained the differences between groups were determined by the size of the Akaike information criterion (AIC) of the models. Only variables that contributed with explanatory power and decreased the size of the AIC were included in the final models.

Variables related to the characteristics of the piglet (piglet-related variables) that were tested included body mass index, ponderal index, birth weight, relative birth weight, crown to rump length, IUGR category (1, 2, or 3), and gender (male or female). All males were denoted males throughout the analyses, although all males alive at d 4 were castrated. A series of characteristics related to the biological mother (sow-related variables), such as litter size, parity (1 to 2, 3, or 4 to 6), gestation length (<116, 116, or >116 d), obstetric assistance (yes or no), and rectal temperature 2 d after farrowing (<38°C or ≥38°C), was also included in the analyses to use all available information. Litter size in the current analyses and discussion only refers to litter size at birth because all litters were subsequently equalized to the same number of piglets. Gestation length and parity were grouped according to their distribution to achieve balanced groups.

Causes of piglet mortality and distribution of stomach content were analyzed by chi-squared distribution.

Figure 2. Illustrations of a normal (left) and a growth-restricted piglet (right). Criteria for growth restriction were 1) steep, dolphin-like forehead, 2) bulging eyes, and 3) wrinkles perpendicular to the mouth. IUGR = intrauterine growth restriction. See online version for figure in color.
Physical characteristics of neonatal piglets

Growth performance was analyzed using a mixed linear model, with ADG from birth to d 26 as response. In addition to the variables that were included in the analyses of survival, the analysis of growth performance included treatment with antibiotics (yes or no) and a variable describing the movement status of piglets (not moved, moved d 0 to 1, or moved after d 1). Moreover, the biological sow was included as a random effect. By use of the methodology applied in the analyses of survival a forward selection process yielded a model that included birth weight, antibiotic treatment, movement, and an interaction between birth weight and movement.

RESULTS

The sows gave birth to 3,402 piglets, of which 2,554 survived to weaning (SURV). The number of stillborn piglets was 256 (STILL), corresponding to an average rate of 1.3 stillborn piglets/litter. Of the 3,146 live-born piglets, 518 died before weaning (DBW), resulting in a preweaning mortality of 16.5% (2.6 piglets/litter) and a total mortality of 22.8% (3.8 piglets/litter). A large proportion of live-born piglets died within 24 h of farrowing or the day after (291 piglets, or 56% DEAD1), whereas another 227 piglets died in the remaining period until weaning (DEAD26). Of the 2,554 surviving piglets, 822 were moved as part of litter equalization, and 194 were cross-fostered later. A total of 74 piglets were removed from the analyses because these piglets could not be accurately classified into groups or were unaccounted for at the end of the registration period.

Postmortem Examination

Postmortem examination was performed on 774 piglets. The postmortem examination showed that crushing was the main cause of death of live-born piglets (Fig. 3). In total, 60%, 25%, 14%, and 1% of live-born deaths were classified as crushed, weak, other causes, and starvation, respectively. There was no difference in the proportion of dead piglets that were crushed to death between d 0 to 1 and d 2 to 26 (60% vs. 59%; $\chi^2 = 0.05$, $P = 0.82$). Evaluation of the stomach contents of the dead piglets (Fig. 3) showed that 48% of live-born piglets that died between birth and weaning had no milk in their stomach, 20% had little milk, 25% had more than half-full stomachs, and 5% had full stomachs. The proportion of piglets that died with completely empty stomachs was greater on d 0 to 1 than d 2 to 26 (64% vs. 28%; $\chi^2 = 65.18$, $P < 0.001$).

Comparing piglets that died due to crushing and due to other reasons between d 0 and 1 indicated that 48% of crushed piglets died with an empty stomach and that 89% of piglets that died due to other reasons had an empty stomach ($\chi^2 = 50.62$, $P < 0.001$). Similarly, 21% of crushed piglets between d 2 to 26 had empty stomachs, whereas 38% of piglets that died from other reasons had empty stomachs ($\chi^2 = 7.41$, $P = 0.007$).

Survival of Piglets (Model 1)

Each survival group was described by mean values of all tested characteristics, both piglet and sow related. Results are listed in Table 2 according to the degree of

### Table 1. Final models used to analyze differences between groups

<table>
<thead>
<tr>
<th>Item</th>
<th>1: SURV vs. DEAD26 vs. DEAD1 vs. STILL</th>
<th>2: SURV vs. DBW</th>
<th>3: DEAD26 vs. DEAD1</th>
<th>4: DEAD1 vs. STILL</th>
<th>5: SURV vs. DEAD26</th>
<th>6: SURV vs. DEAD1</th>
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1Only variables that contributed with explanatory power and decreased the size of the Akaike information criterion were included in the final model. SURV = piglets surviving to weaning; DBW = piglets that died between birth and weaning; DEAD1 = piglets that died within d 0 to 1 after farrowing; DEAD26 = piglets that died between d 2 and 26 after farrowing; STILL = stillborn piglets; X = variables included in the particular model; IUGR = intrauterine growth restriction.
explanatory power and the level of significance of each characteristic when individual characteristics were fitted as the sole explanatory variable of model 1. On an individual basis, piglet-related variables had more explanatory power than those related to the sow. Information about individual physical characteristics of piglets yielded better predictions of survivability than information about the sow or the litter as a whole. Differences between all groups were described by model 1, which included body mass index ($P < 0.001$), litter size ($P = 0.001$), gender ($P < 0.001$), and IUGR score ($P < 0.001$; Table 1).

Model 1 was used to investigate which characteristics defined the overall difference between the 4 groups (SURV, DEAD26, DEAD1, STILL). Subsequent analyses of pairs of groups (models 2, 3, 4, 5, and 6) showed which characteristics described differences between other groups.

Surviving vs. Dead from Birth to Weaning (Model 2)

Piglets in SURV differed from piglets in DBW in body mass index ($P < 0.001$), gender ($P < 0.001$), and parity of the sow ($P = 0.017$; Table 1). Males had greater risk of dying than females (odds ratio = 1.7, $P < 0.001$). Piglets in DBW had a lower body mass index than surviving piglets, and they were born to younger sows (Table 2). Piglets born to sows of parity 3 or parity 4 to 6 had a lower probability of dying than litters from sows of parity 1 to 2 (parity 3: odds ratio = 0.7, $P = 0.017$ and parity 4 to 6: odds ratio = 0.7, $P < 0.014$).

Dead d 0 to 1 vs. Dead d 2 to 26 (Model 3)

Differences between DEAD1 and DEAD26 were described by model 3, which included birth weight ($P = 0.007$), body mass index ($P < 0.001$), and IUGR score ($P = 0.040$) as explanatory variables (Table 1). Piglets in DEAD1 were lighter, had a smaller body mass index, and had a greater IUGR score than piglets in DEAD26. The proportion of growth-restricted piglets (score 3) was too small compared with the proportion of normal piglets to estimate odds ratios of dying for piglets with a score of 1 compared with piglets with a score of 3. However, piglets that displayed some signs of growth restriction (score of 2) had a greater risk (odds ratio = 1.8, $P = 0.036$) of being in DEAD1 than normal piglets (score of 1). Besides a greater birth weight than piglets in DEAD1, the body mass index corresponding to any given birth weight was greater for piglets in DEAD26 than for piglets in DEAD1. In other words, piglets of equal birth weight did not have equal chances of survival if they differed in body mass index.

Dead d 0 to 1 vs. Stillborn (Model 4)

Apart from being different from DEAD26, DEAD1 was also different from STILL. Differences between STILL and DEAD1 included crown to rump length ($P < 0.001$), relative weight in litter ($P = 0.001$), gestation length ($P = 0.008$), and whether or not the sow had increased rectal temperature on d 2 ($P = 0.001$; Table 1). Piglets in STILL were longer and deviated less from the mean weight of the litter than piglets in DEAD1, indicating that piglets in STILL were disproportionately long and thin. The risk of being STILL compared with DEAD1 was less (odds ratio = 0.5, $P = 0.001$) for piglets born to a sow with a rectal temperature of less than 38°C on d 2 after parturition. The risk of being STILL was also lower for piglets born on d 116 (odds ratio = 0.46, $P = 0.003$) or later (odds ratio = 0.5, $P = 0.013$). There was no ($P = 0.42$) difference in the risk of being STILL between piglets born on d 116 and piglets born later than d 116.

Surviving vs. Dead d 2 to 26 (Model 5)

The difference between SURV and DEAD26 was best described by birth weight ($P < 0.001$), gender ($P = 0.004$), parity of the sow ($P = 0.004$), and gestation length ($P = 0.014$; Table 1). Piglets in SURV had a greater birth weight than piglets in DEAD26 (Table 2). Female piglets had a decreased risk of dying within d 2 to 26 compared with males (odds ratio = 0.7, $P = 0.005$). Piglets born before d 116 of gestation had an increased risk of dying compared with piglets that were born after a gestation of 116 d (odds ratio = 1.6, $P = 0.022$) and to piglets born after a gestation of more than 116 d (odds ratio: 1.7, $P = 0.004$). Piglets that were born to parity 1 to 2 sows had an increased risk of
dying between d 2 and 26 compared with piglets born to sows of parity 4 to 6 (odds ratio = 1.7, \( P = 0.002 \)).

**Surviving vs. Dead d 0 to 1 (Model 6)**

Differences between SURV and DEAD1 were best described by body mass index (\( P < 0.001 \)), IUGR score (\( P = 0.004 \)), gender (\( P < 0.001 \)), and litter size (\( P = 0.005 \); Table 1). Piglets in DEAD1 had a smaller body mass index than piglets in SURV and were born in larger litters (Table 2). Piglets with signs of growth restriction had an increased risk of dying on d 0 to 1 (odds ratio = 1.9, \( P = 0.001 \)) compared with normal piglets, and female piglets had a decreased risk of dying compared with males (odds ratio = 0.5, \( P < 0.001 \)).

**Growth Performance**

The weaning weight of piglets averaged 7.1 ± 0.03 kg, which corresponded to an ADG of 223 ± 1.1 g/d. Weight gain of the individual suckling pig was affected by birth weight (\( P < 0.001 \)), treatment with antibiotics (\( P < 0.001 \)), movement status (\( P = 0.014 \)), and an interaction between birth weight and movement status (\( P < 0.001 \)). An increase in birth weight increased ADG, whereas treatment with antibiotics and movement had negative effects on ADG. Furthermore, there was a greater negative effect of movement status for piglets of greater birth weights than for piglets of lower birth weights (Fig. 4). The ADG of piglets that had been treated with antibiotics was lower (\( P < 0.001 \)) than for piglets that were not treated with antibiotics (233 ± 2.92 g vs. 198 ± 2.53 g).

**DISCUSSION**

The results confirmed the hypothesis that the physical characteristics of piglets were related to survivability and also showed that the importance of different characteristics depended on the time of death. Separating dead piglets into subgroups according to time of death yielded more elaborate descriptions of the differences between groups. The results suggested that piglets did not have an equal risk of dying in different periods, even though the cause of death appeared to be similar across time periods. Physical characteristics were less important for growth performance than for survival; instead, the results suggested that management-related characteristics were important for ADG of suckling piglets.

![Figure 4. Calculated ADG according to birth weight for piglets that were not moved (solid line), were cross-fostered d 0 to 1 (dashed line), and were cross-fostered after d 1 (dotted line).](image-url)


**Cause of Death**

As has been seen in previous studies, the majority of piglets in DBW died within the first day of life, and crushing was the predominant cause of death (Marchant et al., 2000; Jarvis et al., 2005). The findings of the current study were similar to the findings of Andersen et al. (2011) in relation to the proportion of piglets that died due to crushing and other reasons. However, in this study, only 1% of DBW appeared to have died from starvation, which is considerably less than the 26% reported by Andersen et al. (2011) and 20% reported by Marchant et al. (2000). This difference can be explained by the use of different categories of cause of death. In this study, 25% of DBW were classified as weak, a category that neither Marchant et al. (2000) nor Andersen et al. (2011) used. The staff often euthanized these weak piglets because they were assessed unable to survive on their own until weaning. The results showed that especially weak piglets often had empty or very little content in their stomach, indicating that they were weak because they were starving. The nutritional importance of adequate intake of colostrum to meet the energy requirements of the neonatal piglet has previously been emphasized (Dividich et al., 2005), and this was supported by the findings in this study. A large proportion of piglets in DEAD1 had empty stomachs, indicating that the nutrient intake of these neonatal piglets had been inadequate. The nutritional status of the piglet has been described as a predisposing factor of mortality (English and Smith, 1975; Dyck and Swierstra, 1987; Tuchscherer et al., 2000). Starving piglets had an increased risk of getting crushed (Weary et al., 1996a), and a large proportion of crushed piglets were found to have no milk in their stomach (Pedersen et al., 2006; Andersen et al., 2011). In accordance with this, a large proportion of piglets that died due to crushing had an empty stomach in this study. Many of the weak piglets that died with empty stomachs were, as previously mentioned, euthanized by the staff. Had the staff not intervened, these piglets may have died due to crushing or starvation instead. The fact that staff were allowed to euthanize piglets may have affected the results regarding the cause of death of piglets.

**Body Mass Index**

The analyses showed that body mass index explained differences between several groups in this study, and a high body mass index indicated improved survivability of piglets. The ability of body mass index to explain differences between SURV and DBW was likely offset by the difference between SURV and DEAD1, as body mass index was not a significant descriptor of differences between SURV and DEAD26. Previous studies have found birth weight to be superior to body mass index as an indicator of survival (Baxter et al., 2008, 2009). These studies did, however, use rooting response (a measure of vigor) and latency to suckle (Baxter et al., 2008) or rectal temperature at 1 h after birth (Baxter et al., 2009) in the final models; thus, these factors may explain greater variation than body mass index. The ability to regain heat and acquire colostrum is essential for survival of neonatal piglets (Herpin et al., 2002), and the results in this study support these findings because many piglets died with empty stomachs. The relationship between body mass index and behavioral and physiological observations could not be established in this study, but these findings suggest that piglets with a high body mass index were those that were capable of achieving an adequate nutritional uptake and were not subjected to physiological challenges, such as hypothermia. Moreover, in the current study, it was observed that 2 piglets of equal birth weight did not have equal risk of dying if they differed in body mass index. If they were of equal birth weight, the piglet with the greatest body mass index had an improved chance of survival.

In an investigation where piglets of similar genetics had different genetic merit for survival, piglets with a high genetic merit for survival had similar BW as those with low merit for survival but were shorter, had greater muscle and liver glycogen concentrations, and greater body fat percentage (Leenhouders et al., 2002b). Herpin et al. (1993) suggested that piglets selected for lean tissue growth displayed a delayed maturity because they were born with a lower body fat percentage and that this was detrimental for survival. Perhaps the body mass index of a piglet is associated with its body fat percentage, and this might explain why body mass index is important in relation to survivability. Leenhouders et al. (2002b) attributed a greater survival to a greater degree of prenatal development. Throughout gestation, the BW gains of fetuses follow an exponential curve, whereas fetal length increases according to a more linear course (Biensen et al., 1998). Prenatal development could therefore be expressed as more weight for length, which is reflected by an increased body mass index of the piglet. This is also in accordance with results regarding gestation length in the current study, where a shorter gestation had a negative impact on survivability of piglets. Previous investigations have shown that a shorter gestation length reduced the birth weight of piglets (Gunvaldsen et al., 2007; Rydhmer et al., 2008; Straw et al., 2008) and had a negative impact on preweaning survival (Roche and Kalm, 2000; Rydhmer et al., 2008; Fix et al., 2010). The importance of body mass index in relation to survival of piglets is likely related to prenatal development, and these relations should be elucidated further in future studies.
Previous findings have shown that body mass index was particularly important for prenatal survival (Baxter et al., 2008, 2009). Stillborns were compared with either live-born piglets (Baxter et al., 2008) or piglets surviving to weaning (Baxter et al., 2009). Investigating prenatal survival was, however, not an objective of the current study, and the failure of body mass index to explain differences between STILL and DEAD1 might be attributed to the group of comparison. Piglets in STILL were only included in the analyses to establish if piglets in DEAD1 were different from piglets in STILL or if these 2 groups could be regarded as similar from a physical point of view. Results from the current study suggested that other variables were better descriptors of differences between STILL and DEAD1 than body mass index. Had STILL been compared with either live-born piglets or piglets in SURV, they would likely differ in body mass index, as body mass index was the variable that had the most explanatory power of all variables in the analyses. Moreover, STILL differed in characteristics related to BW and length, which indicated that body conformation was of importance for prenatal survival.

It seems that body conformation was important for piglet survival and that body mass index could be a potential indicator of survivability in farrowing pens. This also suggests that body conformation was more important than birth weight and that to improve survivability of piglets, it is not sufficient to focus on birth weight alone. Additional knowledge is required about the relation between body mass index and other factors and how body mass index is possibly affected.

**Gender**

Males were more likely to die between birth and weaning than females, which is in accordance with results presented by Roehe and Kalm (2000). Some of the increased risk of dying for male piglets in the current study may be explained by surgical castration. Castration was performed routinely and has been associated with an increased risk of infection (Strom, 1996). However, mortality for males in both the DEAD1 (piglets not yet been castrated) and DEAD26 (piglets might have been castrated) categories was increased compared with females. In an outdoor system where piglets were not castrated, a significantly greater proportion of males died from birth to weaning compared with females (Baxter et al., 2009, 2012). The results of the experiments by Baxter et al. (2009, 2012) suggest that male piglets may be disadvantaged in ways other than castration. An experiment that evaluated physiological and behavioral traits of 135 piglets born to 10 sows did not find a difference in prenatal and postnatal survival between male and female piglets (Baxter et al., 2008). Tuchscherer et al. (2000) did not find a difference in blood chemistry and immunity of male and female piglets at birth. It has been suggested that the increased risk of dying for male piglets was caused by testosterone, which increased the energy-expensive processes of degrading and producing protein (Vaillancourt and Tubbs, 1992), causing male piglets to have less energy available to regain body temperature and acquire colostrum. This was supported by a study of teat-seeking ability where male piglets suckled later than female piglets (Bate et al., 1985).

Male piglets have been found to have greater birth weights than female piglets (Roehe and Kalm, 2000; Tuchscherer et al., 2000), which is likely to diminish the effect of gender on mortality (Roehe and Kalm, 2000). Males and females may differ in other characteristics associated with the risk of dying as well, but this has yet to be studied. The proportion of male to female piglets in a litter can hardly be altered, but why male piglets may have an increased risk of dying compared with females should be investigated further. Knowing why male piglets are compromised can lead to proper handling of male piglets and thus possibly decrease their risk of dying.

**Intrauterine Growth Restriction**

Investigations of the effects of growth restriction where physically identifiable signs have been used to define growth-restricted piglets are limited. Methods for identification of growth-restricted piglets have used the birth weight of piglets to define growth restriction, by defining either piglets with a birth weight between the 5th and 10th percentiles or piglets below 1.5 SD of mean birth weight as growth restricted (Bauer et al., 1998, 2003; D’Inca et al., 2010). Hence, in these studies, growth-restricted piglets may experience the extremes of the difficulties of being small. Growth-restricted piglets may display a lower degree of vitality (De Roth and Downie, 1976), be less competitive at the udder (Hoy et al., 1994), and be less resistant to cold (Dividich et al., 2005) simply because they are small. Other reported consequences of growth restriction include physiological implications, such as changes to renal and cardiovascular function and affected muscular development, which are also expected to affect mortality of piglets at both early and later stages of life (Bauer et al., 2003; Town et al., 2005; D’Inca et al., 2010). Compared with normal piglets, piglets displaying signs of IUGR in this study had 1.8 times greater risk of being in DEAD1 than in DEAD26, indicating that the first days of life were particularly challenging for growth-restricted piglets. This was further supported by the comparisons of SURV with DEAD1 and DEAD26. The degree of growth restriction (IUGR category) only explained differences between SURV and DEAD1 and not between SURV and
DEAD26, confirming that more piglets in DEAD1 than in DEAD26 displayed signs of growth restriction. The results indicated that IUGR piglets could be identified immediately after birth. Because growth-restricted piglets had a high risk of dying in the first days of life, actions to improve the survivability of these piglets should be taken immediately after farrowing.

**Birth Weight**

Several studies have reported a favorable relationship between increased birth weight and survival (van der Lende and de Jager, 1991; Roehe and Kalm, 2000; Wolf et al., 2008). Accordingly, results in this study showed that birth weight was a descriptor of differences between SURV and DEAD26, as well as differences between DEAD26 and DEAD1. The relationship between birth weight and mortality was studied in a pen system where a quadratic relationship was found, and the risk of crushing has also been found to decrease with increasing birth weight (Jarvis et al., 2005; Pedersen et al., 2011). Small piglets were more likely to stay in close proximity to the sow, improving their chances of getting milk but also increasing the risk of crushing (Weary et al., 1996b). Furthermore, smaller piglets have a larger surface-to-body ratio, which makes them more susceptible to hypothermia (Herpin et al., 2002). Supporting this hypothesis of Herpin et al. (2002) are studies showing that piglets dying from hypothermia were lighter at birth than piglets dying from other causes (Marchant et al., 2000). Birth weight is a well-established indicator of survival, but results from this study suggest that other parameters that include more information about both the weight and size of the piglet may prove more efficient as indicators of survival.

Birth weight was the only piglet-related characteristic that influenced growth performance. An increase in birth weight yielded an increase in ADG, which agrees with previous results (Quiniou et al., 2002; Bergstrom et al., 2009; Beaulieu et al., 2010). The birth weight of a piglet reflects the prenatal development of muscle fibers (Rehfeldt et al., 2000); thus, it is not surprising that a greater birth weight yields an increased growth rate. Results of the present study indicated that management-related characteristics may influence the growth of piglets. Larger piglets are more likely to engage in teat fights (Hartsock et al., 1977; Horrell and Bennett, 1981), and this could explain why the consequences of movement seem to be more detrimental for the growth performance of larger piglets than for smaller piglets. The reason why the piglet is moved might also be important. When a small piglet is moved, it is probably moved to better conditions to improve survival and general well-being (Milligan et al., 2001). A larger pig is, on the other hand, expected to do well even in difficult conditions and is not necessarily moved to better conditions (Price et al., 1994). Consequently, a larger piglet might have to engage in more fights and withstand greater challenges than a smaller piglet to cope with the new environment.

**Relative Birth Weight**

Relative weight of piglets has previously been used to define low-birth-weight piglets in a litter, and piglets with a low relative birth weight had an increased risk of dying (Milligan et al., 2002). In the current study, relative birth weight was inferior to absolute birth weight and body mass index in relation to survival from birth to weaning because it only explained differences between DEAD1 and STILL. These results indicated that absolute birth weight was a better indicator of survivability than the relative birth weight, which is consistent with the findings in van der Lende and de Jager (1991). Moreover, the findings of the current study suggested that the smallest piglet in a litter was at increased risk of dying shortly after birth, but not of being stillborn. Previous studies have associated low birth weight with hypoxia and stillbirth (Herpin et al., 1993; Leenhouwers et al., 2003; Pedersen et al., 2011). This is in contrast to the results of Le Cozler et al. (2002), who did not find an increased probability of stillbirth for piglets of lighter birth weights. Similarly, in the current study, birth weight did not explain the differences between DEAD1 and STILL; hence, birth weight alone was not a good indicator of the risk of dying prenatally or shortly after birth. Results may, however, be affected by the groups of comparison as both DEAD1 and STILL had the lightest birth weights, and had STILL been compared with other groups, results would likely be more in accordance with other studies. Results showed that the relative weight of a litter was of importance in the first days after birth and that attention should be given to the lightest piglets in a litter immediately after birth to increase their survivability.

**Crown to Rump Length**

Piglets selected for a high genetic merit for survival have been found to be shorter than those with a low merit for survival (Leenhouwers et al., 2002a,b). Crown to rump length failed to explained differences in preweaning survivability in the current study, which was likely due to the superiority of body mass index, which included both the weight and length of the piglet. This is consistent with the findings of Leenhouwers et al. (2002a,b), where piglets with a high genetic merit for survival also had more weight for length.

The results demonstrated that piglets in DEAD1 were shorter than piglets in STILL. Baxter et al. (2008, 2009)
described stillborn piglets as disproportionately long and thin, indicating that they had less BW for length. This description also appears to fit STILL in this study because they deviated less from the mean weight of the litter but were longer than DEAD1. The current study also included relative birth weight, which was not available in Baxter et al. (2008, 2009), and the combination of length and relative BW may, to some extent, explain the same differences in the body proportions as body conformation indices did in Baxter et al. (2008, 2009). In the present study, some characteristics of STILL were similar to SURV (e.g., crown to rump length), whereas other characteristics were more similar to DBW (e.g., birth weight). Thus, these results showed that the length of a piglet was important in the prediction of survival, especially when information about the weight was also available. In addition to the lightest piglets in the litter being at an increased risk of dying shortly after birth, shorter piglets also seem to have an increased risk of dying shortly after birth.

**Litter Size**

Several studies have found large litter sizes to have negative effects on preweaning survival (Weary et al., 1998; Roehe and Kalm, 2000; Pedersen et al., 2006). Results from the current study suggested that increased litter size was associated with an increased risk of dying in the first days of life. However, there was no evidence of litter size influencing the risk of dying in the latter part of the preweaning period, as piglet-related variables were superior in explanatory power. One of the consequences of larger litter sizes is decreased birth weights of piglets (Kerr and Cameron, 1995; Wolf et al., 2008; Pedersen et al., 2011).

Litter size had no explanatory power in the model of DEAD1 vs. STILL, suggesting that litter size was equal in these 2 groups. Previous studies on the influence of litter size on prenatal survival have reached ambiguous conclusions. Some have not reported a relation between increased litter size and increased risk of stillbirth (Baxter et al., 2009; Pedersen et al., 2011), whereas others have found a negative impact of larger litter size on prenatal survival (Zaleski and Hacker, 1993; Leenhouders et al., 1999; Pedersen et al., 2006). The effects of litter size may have been expressed indirectly as effects of body mass index, birth weight, birth interval, and birth order in Baxter et al. (2009) and Pedersen et al. (2011). In addition to a possible effect of litter size on individual physical characteristics, results from the current study suggested that the relation between large litters and preweaning death was more pronounced for piglets dying shortly after birth.

**Parity**

In this study, piglets born to sows of parity 1 to 2 had a greater risk of being in DBW than piglets born to sows of parity 3 or parity 4 to 6, which is in accordance with Wulbers-Mindermann et al. (2002), who found a greater risk of dying (odds ratio = 2.3) for piglets born to primiparous sows compared with piglets born to multiparous sows. In contrast, Roehe and Kalm (2000) reported a greater risk of dying if piglets were born to sows of parity 2, 3, 4, or 5 compared with piglets that were born to parity 1 sows. This is in accordance with several studies where results showed an increased mortality and an increased prevalence of crushing with increasing parity (Roehe and Kalm, 2000; Jarvis et al., 2005; Weber et al., 2009). Individual parities were not tested in the present study because parities followed a skewed distribution. Inclusion of individual parities rather than the classification that was used in the current study might yield results in agreement with other studies. Moreover, sows were housed in groups before placement in the farrowing pens, and the insertion in individual pens may have stressed gilts more than sows. Studies have shown that previous environment may affect the periparturient behavior of gilts (Beattie et al., 1995; Harris and Gonyou, 1998; Boyle et al., 2000) and that gilts had a greater prevalence of near-crushing situations during the first 48 h after parturition than multiparous sows (Pedersen and Jensen, 2008). Thus, the decreased degree of previous experience with the farrowing pens may have affected the younger sows negatively.

In conclusion, preweaning survival of piglets born in a noncrate system was affected by individual physical characteristics of the piglets. Survival to weaning was improved if piglets were females, had a high body mass index, and were born to sows of parity 3 or more. Different periods were introduced to investigate the effects of physical characteristics during different periods of the preweaning period, and the results showed that the importance of individual characteristics were not ranked identically in different periods of the preweaning period. The findings of this study suggested that different characteristics could be applied as risk factors in different periods of the preweaning period and that improvements in survival should be approached according to the specific periods. Finally, the results of this study also suggested that management of piglets was important in relation to growth performance and that physical characteristics had less influence on the weight gain of suckling piglets.

**LITERATURE CITED**


