Effects of the Level of Asphyxia During Delivery on Viability at Birth and Early Postnatal Vitality of Newborn Pigs

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ABSTRACT: Newborn pigs (n = 117) were used to provide information on the relationships of degree of asphyxia during delivery, viability at birth, and some striking aspects of postnatal vitality including survival, interval between birth and first udder contact and between birth and first suckling, rectal temperature at 24 h of life (RT24), and growth rate over the first 10 d of life. The degree of asphyxia at birth was estimated from cord blood pCO2, pH, and lactate levels. Onset of respiration, heart rate, skin color, and attempts to stand during the first minute after birth were used to estimate the viability score. Neonatal asphyxia, i.e., decreased blood pH and increased blood pCO2 and lactate, was associated with the production of unusually high levels of catecholamines. The degree of asphyxia increased with late position in the birth order (P < .01) and was higher in piglets born posteriorly (P < .05). Further, the average blood pCO2 within a litter increased (P < .05) with litter size. There was an inverse relationship between the degree of asphyxia and the viability score (P < .001). Highly viable piglets reached the udder more rapidly (P < .001) and had a higher RT24 (P < .001) than those of low viability. Plasma glucose concentrations increased with blood pCO2 and plasma epinephrine concentrations (P < .001). Neonatal asphyxia reduced postnatal vitality by delaying the first contact with the udder (P < .03) and was associated with a lower RT24 (P < .05), growth rate (P < .001), and survival over 10 d (P < 0.06). These variables, i.e., interval between birth and first udder contact, RT24, and growth rate, were correlated with birth weight (P < .001); RT24 was also shown to decrease (P < .001) with the time taken to reach the udder. Overall, results suggest that piglets suffering from asphyxia during delivery are less viable at birth and less prone to adapt to extra-uterine life.

Key Words: Asphyxia, Parturition, Piglets, Viability, Postnatal Vitality

Introduction

During delivery, a moderate degree of asphyxiatio

stillbirths are predominantly a result of fetal asphyxi


tion is normal in all fetuses (James, 1960). However, in polytocous species such as the pig, later-born piglets are likely to suffer to a greater degree from asphyxia

tion because of the cumulative effects of successive

contractions in reducing the oxygenation of the unborn

piglets, and because of the greater risk of occlusion,

damage, or rupture of the umbilical cord or of

detachment of the placenta as delivery progresses (English and Wilkinson, 1982). In fact, intrapartum

the degree of asphyxia during delivery, the viability at birth, and some striking aspects of early postnatal vitality including survival, birth to first contact with the udder interval, rectal temperature at 24 h (RT24), and growth rate over 10 d.

Materials and Methods

Animals. One hundred seventeen newborn Piétrain × Large White crossbred pigs from 11 sows were used in this project. The sows were of second parity or more. Management of the sows and piglets during pregnancy and lactation was typical of current practice. Sows farrowed naturally without any previous injection of prostaglandin F2α or oxytocin, and although all farrowings were attended and supervised, sow and piglets were not assisted and medical intervention was minimal during delivery. This means that vaginal exploration was only performed when birth interval exceeded 3 h and that piglets born inside the membranes and weak piglets were not assisted in establishing respiration and to suckle. This was supposed to give the best estimate of the natural variability and consequences of intrapartum asphyxia. The piglets were ear notched after birth. As each piglet was born, the exact time of birth, sex, presence of membranes and presentation (anterior or posterior) were recorded and the umbilical cord was clamped, observations were made on four measurements in order to estimate the degree of intrapartum asphyxia. The piglets were ear notched after birth. As each piglet was born, the exact time of birth, sex, presence of membranes and presentation (anterior or posterior) were recorded and the umbilical cord was checked (normal or broken).

Blood Sample Collection and Analysis. Blood samples were collected during the period of apnea preceding the onset of respiration, i.e., within 10 s after birth while the piglet was still lying at the back of the sow. The umbilical cord was ruptured and 1 mL of the collected blood was immediately transferred in a heparinized blood gas syringe (Marquest Medical Products, Englewood, CO) that was sealed and kept on ice for a maximum of 2 h before analysis, in conformity with the stability of blood gas measurements (Zaleski and Hacker, 1993b). Because blood samples could have been slightly contaminated by air during the few seconds of collection, partial pressure of oxygen (pO2) and oxygen saturation of hemoglobin (SO2) were not analyzed. However, considering that blood oxygenation was changing within seconds as soon as the piglet started to breathe (SO2 and pO2 increased sevenfold in the umbilical artery during the first 4 min of life; our unpublished observations) and that changes in blood pCO2, pH concentrations and lactate concentrations were much less pronounced (blood pCO2 decreased by 20% and pH and lactate concentrations did not change during the first 4 min of life in the umbilical artery; our unpublished observations), we assumed that this simple and quick procedure of blood collection was adequate to estimate the degree of intrapartum asphyxia from blood pCO2, pH, and lactate concentrations at birth (Randall, 1971), without causing disturbances to the piglet. The remaining blood was either kept on ice for further determination of blood lactate concentrations (.2 mL) or centrifuged at 13,000 × g for 3 min at 4°C for the determination of plasma glucose, epinephrine, and norepinephrine concentrations (1 mL).

Blood content and oxygen saturation of hemoglobin were measured on a Ciba-Corning 270 CO-oximeter (Ciba-Corning Diagnostics, Cergy Pontoise, France) with specific parameters for neonatal pig blood. Blood gases and pH were analyzed simultaneously using a Ciba-Corning 278 Blood Gas System, which allows correction for the actual pig body temperature. Rectal temperature was measured at birth using a digital display thermometer (model BAT 8, Bayley Instruments, Saddle Brooks, NJ) and a polyethylene-covered probe inserted 7 cm into the rectum. Blood lactate was determined by the lactate oxidase method using an automatic analyzer (YSI 27, YSI Corporated, Yellow Spring, OH) and plasma glucose by the glucose oxidase method using a commercial kit (Glucose enzymatique PAP, Bioméérieux, Marcy l’Etoile, France). Plasma catecholamines were analyzed by HPLC with electrochemical detection after purification and concentration of the amines on alumina, as described by Bertin et al. (1990).

Viability at Birth and Early Postnatal Vitality. When 15 s had elapsed from birth, i.e., when blood was collected and the umbilical cord clamped, observations were made on four measurements in order to estimate the viability of the piglet according to a simplification of the scoring system described by Randall (1971): heart rate (absent or regular), onset of respiration (absent or established), skin color (pale, cyanotic, or pink), and attempts to stand until 1 min after birth. Four viability classes were then defined as follows: 1) stillborn, piglet having no detectable heart rate and making no attempts at respiration; 2) low viability, piglet with weak and irregular respiration and(or) pale color and making no attempts to stand; 3) medium viability, piglet with regular respiration and normal color but making no or very few attempts to stand; 4) high viability, piglet with regular respiration and normal color and making intense attempts to stand.

The components of the viability score reflect the piglet’s chances of survival; however, neonatal survival relies also on the ability of piglets to thermoregulate and to “obtain” an early intake of colostrum. Therefore, as suggested by various authors (Bunger et al., 1984; Junghans, 1992; Hoy et al., 1994, 1995a,b), the following items were measured to estimate early postnatal vitality: interval between birth and first udder contact, interval between birth and first suckling, rectal temperature at 24 h of life (RT24), survival and growth rate over the first 10 d of life. Piglets were weighed after the first suckling and at 1 and 10 d of age.

Statistical Analysis. Data obtained on stillborn pigs were not included in the analysis, except when
comparisons were made between the four viability classes. Regressions were computed using the REG procedure of SAS (1988) to determine the nature (linear or quadratic) of the relationships among 1) blood measurements at birth and farrowing traits (duration of farrowing, position in the birth order, birth interval), 2) early postnatal vitality and farrowing traits, 3) early postnatal vitality and blood measurements at birth, 4) early postnatal vitality and birth weight, 5) and blood measurements at birth and birth weight. Multiple regression analysis was performed to determine the best estimate of two parameters: 1) interval between birth and first udder contact and 2) RT24. Variables needed to meet a .05 significance level for entry into the multiple regression analysis model. Analysis of variance (GLM procedure of SAS, 1988) was used to analyze the relations between viability classes and blood measurements at birth, between viability classes and farrowing traits, and between viability classes and postnatal vitality, with viability class as main effect; means were further separated by F-protected LSD. Means ± SE were calculated for the type of presentation (anterior vs posterior), the characteristics of the highly asphyxiated (HA) piglets (HA vs normal), and the characteristics of the piglets that died during the first 10 d of life (dead vs alive), and were compared by Student’s t test, with piglet being the experimental unit. Chi-square analysis (FREQ procedure of SAS, 1988) was performed to analyze the difference in survival rate between HA and normal piglets.

Results

Of the 117 piglets born, 110 (94.0%) were alive at birth, 7 (6.0%) were stillborn, and 25 (21.4%) died during the first 10 d of postnatal life. Of the piglets born alive, 4 (3.6%) were of low viability, 17 (15.5%) of medium viability, and 89 (80.9%) of high viability. Because of technical difficulties (e.g., pCO2 and pH values were not available in the first two litters) and experimental problems (e.g., some piglets were born simultaneously, and data on first contact with the udder were not available in one litter due to the aggressivity of the sow), data from only 80 to 100 piglets are reported throughout this report.

Degree of Asphyxiation and Progress of Parturition. As shown in Figure 1, there was considerable variation in the degree of asphyxiation suffered by the piglets during delivery, as reflected by blood lactate ranging from 15 to 90 mg/dL, blood pCO2 from 45 to 180 mm Hg, and blood pH from 6.7 to 7.4 at the time of birth. These variables were linearly correlated, with a correlation coefficient of -.91 (P < .001) between blood pH and lactate and .74 (P < .001) between blood pCO2 and lactate (Figure 1), and were adequate criteria to evaluate the degree of neonatal asphyxia. Plasma concentrations of epinephrine (YEP) and norepinephrine (YNOR) were high at birth, averaging 12.8 and 68.0 ng/mL, respectively, and were correlated with blood pCO2 (XCO, mm Hg) by the following equations:

\[ YEP = .83 (± .08) XCO - 41.14 (± 5.86) \]

\[ (n = 68, r = .77, P < .001); \]

\[ YNOR = 8.70 (± .60) XCO - 483 (± 42) \]

\[ (n = 68, r = .87, P < .001). \]

Duration of farrowing (YDF) and average blood pCO2 within a litter (YACO) were related to the number of piglets per litter (XNP) by the following equations:

\[ YDF = 12.96 (± 4.46) XNP - 6.87 (± 56.65) \]

\[ (n = 11, r = .74, P < .05); \]

\[ YACO = 1.11 (± .44) XNP + 49.59 (± 5.60) \]

\[ (n = 11, r = .69, P < .05). \]

In addition, blood pCO2 increased (n = 84, r = .29, P < .05) and blood pH decreased (n = 80, r = -.33, P < .05) slightly with position in the birth order (Figure 2). Plasma norepinephrine was also slightly related to position in the birth order (n = 80, r = .22, P < .05). No relationship was found between birth interval, sex, or weight of the piglet and degree of asphyxia, except that blood lactate (YLAC, mg/dL) was inversely related to birth body weight (XBW, g) by the following equation:

\[ YLAC = -0.022 (± .008) XBW + 66.5 (± 10.6) \]

\[ (n = 81, r = -.33, P < .01). \]
Figure 2. Effect of the position of the piglet in the birth order on cord blood pCO\textsubscript{2} (mm Hg) and pH at the time of delivery. Blood pCO\textsubscript{2} (Y\textsubscript{CO}) increases with birth order (X) according to the following equation: Y\textsubscript{CO} = 1.58 (± .62) X + 55.42 (± 4.74); n = 84, r = .29, P < .05. Blood pH (Y\textsubscript{PH}) decreases with birth order according to the following equation: Y\textsubscript{PH} = −.013 (± .005) X + 7.317 (± .038); n = 80, r = −.33, P < .05.

The presentation of the piglet had striking effects on blood and plasma measurements related to the degree of neonatal asphyxia (Table 1). Piglets presented posteriorly (52% of the liveborn pigs) had higher blood lactate concentrations (+55%, P < .01) and pCO\textsubscript{2} (+18%, P < .05) and lower blood pH (P < .05) than those presented anteriorly. In addition, posterior presentations seemed to be more stressful for piglets, as shown by much higher levels of plasma norepinephrine (2.6-fold, P < .07) and epinephrine (two-fold, P < .05).

**Short-term Effects of Neonatal Asphyxia on Plasma Glucose Concentration and Viability at Birth.** There was a curvilinear relationship between plasma glucose concentration and extent of asphyxia in the liveborn pigs, with glucose concentrations increasing with blood pCO\textsubscript{2} (n = 81, R\textsuperscript{2} = .44, P < .001; Figure 3) and decreasing with blood pH (n = 80, R\textsuperscript{2} = .48, P < .001; Figure 4). Plasma glucose concentrations reached a plateau approximately for pH values lower than 7.1 and blood pCO\textsubscript{2} values higher than 100 mm Hg. However, glucose concentrations up to 1,900 mg/L have been found in some stillborn piglets (data not shown). Plasma glucose concentrations (Y\textsubscript{GLU}, mg/L) were also correlated with plasma epinephrine concentrations (X\textsubscript{EP}, ng/mL) by the following equation:

\[
Y_{\text{GLU}} = 5.15 \pm 1.18) X_{\text{EP}} + 578 \pm 33
\]

(n = 75, r = .45, P < .001).

Blood and plasma measurements were extremely different (P < .01) in the four viability classes at birth (Table 2). Highly viable piglets (class 4) exhibited 45% lower blood pCO\textsubscript{2}, 5.7% higher blood pH, 59% lower blood lactate, and 46% lower plasma glucose concentrations than piglets of low viability (class 2) (P < .05); the difference was even more important with born-dead piglets (class 1). A similar effect was observed on plasma catecholamines, with epinephrine and norepinephrine concentrations being five- and ninefold lower, respectively, in piglets with high viability scores than in piglets with low viability scores (P < .001).

Figure 3. Relationship between plasma glucose concentrations (mg/L) and blood pCO\textsubscript{2} (mm Hg) at the time of delivery in piglets. Plasma glucose concentrations (Y\textsubscript{GLU}) increase curvilinearly with blood pCO\textsubscript{2} (X\textsubscript{CO}) according to the following equation: Y\textsubscript{GLU} = −1.01 (±.024) X\textsuperscript{2}\textsubscript{CO} + 26.6 (± 4.89) X\textsubscript{CO} − 613 (± 209); n = 81, R\textsuperscript{2} = .44, P < .001.

Figure 4. Relationship between plasma glucose concentrations (mg/L) and blood pH at the time of delivery in piglets. Plasma glucose concentrations (Y\textsubscript{GLU}) decrease curvilinearly with blood pH (X\textsubscript{PH}) according to the following equation: Y\textsubscript{GLU} = −1.477 (± 708) X\textsuperscript{2}\textsubscript{PH} + 19,956 (± 10,078) X\textsubscript{PH} − 66,338 (± 35,808); n = 80, R\textsuperscript{2} = .48, P < .001.
With regard to the progress of parturition, no relation was found between viability score and birth interval, sex, or weight of the piglets, but piglets born during the early stages of farrowing (first third) were more viable than those presented in the middle and last third (95.5 vs 65.8% of highly viable piglets, respectively, \( P < .01 \)).

Mid-term Effects of Neonatal Asphyxia on Early Postnatal Vitality. Neonatal survival relies, at least in part, on the ability of the piglet to find the udder and ingest colostrum. Our results show that the times between birth and first udder contact and between birth and first colostrum intake averaged 32 ± 4 (\( n = 88 \)) and 44 ± 5 min (\( n = 88 \)), respectively. Both measurements were similarly affected by the degree of neonatal asphyxia, and therefore linear correlation coefficients are presented only for the first measurement (Table 3). The time taken by the piglet to reach the udder increased with blood \( pCO_2 \) (\( P < .02 \)), blood lactate (\( P < .03 \)), and with decreasing blood pH (\( P < .02 \)). This interval decreased with increasing birth weight (\( P < .001 \)). Therefore, the time taken to reach the udder (\( Y_{TRU} \), min) was related to blood \( pCO_2 \) (\( X_{CO_2} \), mm Hg) and birth weight (\( X_{BW} \), g) by the following equation:

\[
Y_{TRU} = 47.58 \pm 31.04 + 0.59 \pm 0.30 X_{CO_2} - 0.043 \pm 0.016 X_{BW} \quad (n = 62, R^2 = 0.20, P < .001).
\]

However, despite the high statistical significance of this relation, blood \( pCO_2 \) and birth weight explained only 20% of the variability in the time taken by the piglet to reach the udder.

Rectal temperature at 24 h averaged 38.2 ± 0.1°C and increased with blood pH (\( P < .001 \)) and with decreasing blood \( pCO_2 \) (\( P < .05 \)) and lactate (\( P < .003 \)) at birth. The \( RT_{24} \) was also shown to increase (\( P < .001 \)) with birth weight and to decrease (\( P < .001 \)) with the time to reach the udder (Table 3). Using multiple regression analysis, it was shown that \( RT_{24} \) (\( Y_{RT24} \), °C) was mainly dependent on the time to reach the udder (\( X_{TRU} \), min), blood lactate (\( X_{LAC} \), mg/dL), and plasma epinephrine (\( X_{EP} \), ng/mL), with the effect of birth weight not significant in the model.

\[
Y_{RT24} = 39.98 \pm 0.48 - 0.023 \pm 0.005 X_{TRU} - 0.049 \pm 0.016 X_{LAC} + 0.028 \pm 0.014 X_{EP} \quad (n = 58, R^2 = 0.42, P < .001).
\]

Finally, the average daily weight gain during the first 10 d of life was positively related to birth weight (\( P < .001 \)) and \( RT_{24} \) (\( P < .01 \)) and inversely related to

### Table 1. Effect of the presentation of the piglet on blood and plasma measurements at birth

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Lactate, mg/dL</th>
<th>( pCO_2 ), mm Hg</th>
<th>pH</th>
<th>Norepinephrine, ng/mL</th>
<th>Epinephrine, ng/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>29.7 ± 2.3</td>
<td>60.3 ± 2.0</td>
<td>7.285 ± 0.019</td>
<td>30.2 ± 10.8</td>
<td>6.1 ± 2.2</td>
</tr>
<tr>
<td>Posterior</td>
<td>45.9 ± 4.3</td>
<td>71.2 ± 4.4</td>
<td>7.187 ± 0.034</td>
<td>109.0 ± 38.7</td>
<td>18.6 ± 4.7</td>
</tr>
</tbody>
</table>

\( P \) value: .01 .05 .05 .07 .05

\( n \) values: 48 39 39 48 35

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood variable(^a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( pCO_2 ), mm Hg</td>
<td>142 ± 26 (3)</td>
<td>108 ± 14 (4)</td>
<td>68 ± 4 (10)</td>
<td>59 ± 1 (66)</td>
<td>.001</td>
</tr>
<tr>
<td>pH</td>
<td>6,598 ± .084 (4)</td>
<td>6,896 ± .075 (4)</td>
<td>7,171 ± .04 (10)</td>
<td>7,291 ± .012 (66)</td>
<td>.001</td>
</tr>
<tr>
<td>Lactate, mg/dL</td>
<td>125 ± 11 (4)</td>
<td>79 ± 8 (4)</td>
<td>49 ± 6 (16)</td>
<td>32 ± 2 (81)</td>
<td>.001</td>
</tr>
</tbody>
</table>

| Plasma variable\(^a\) |     |     |     |     |         |
| Glucose, mg/L         | 1,305 ± 235 (4) | 1,023 ± 65 (4) | 691 ± 88 (14) | 555 ± 22 (79) | .001 |
| Epinephrine, ng/mL    | 44.9 ± 29.8 (3) | 58.6 ± 14.7 (4) | 4.9 ± 1.3 (16) | 10.0 ± 2.8 (58) | .001 |
| Norepinephrine, ng/mL | 708 ± 527 (3) | 376 ± 98 (4) | 28 ± 6 (16) | 38 ± 10 (80) | .001 |

\( ^a \) Values are means ± SE (number of animals). Means were compared by Student’s \( t \) test.

### Table 2. Blood and plasma measurements according to the viability score\(^b\) of the piglet at birth

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood variable(^b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( pCO_2 ), mm Hg</td>
<td>142 ± 26 (3)</td>
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<td>Lactate, mg/dL</td>
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</tr>
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| Norepinephrine, ng/mL | 708 ± 527 (3) | 376 ± 98 (4) | 28 ± 6 (16) | 38 ± 10 (80) | .001 |

\( ^b \) Viability at the time of birth was assigned as described in Material and Methods: 1, born dead; 2, low viability; 3, medium viability; 4, high viability.

\( ^a \) Values are means ± SE (number of animals). Blood was taken from the umbilical cord at birth. Analysis of variance was used to analyze the relations between viability score and blood and plasma measurements, with viability score as main effect. Means were separated by F-protected LSD.
the degree of neonatal asphyxia (P < .001 with blood lactate).

Postnatal vitality was also related to the viability score, in that highly viable piglets (class 4) reached the udder and suckled more rapidly (P < .001), i.e., 25 ± 3 vs 120 ± 35 min and 36 ± 4 vs 125 ± 33 min after birth, respectively, and exhibited a higher RT24 (38.6 ± .1 vs 32.9 ± 2.9°C, P < .001) than piglets of low viability (class 2). Piglets from class 3 exhibited intermediary values in that they reached the udder and suckled 40 ± 12 and 48 ± 15 min after birth, respectively, and had a lower RT24 (37.4 ± .6°C; P < .01) than class 4 piglets. Mortality rate over the first 10 d of life was 17% for class 4 (15/89), 35% for class 3 (6/17), and 100% for class 2 piglets (4/4) (P < .05).

Characteristics of Highly Asphyxiated Piglets at Birth and Piglets Dying Before 10 d of Age. Some piglets seemed to suffer from acute asphyxia during parturition (n = 14) and were therefore classified as HA (Table 4). Average blood measurements of HA piglets at birth were as follows: pCO2 = 88.4 mm Hg, pH = 7.002, lactate = 64.6 mg/dL, epinephrine = 44.5 ng/mL, and norepinephrine = 237.5 ng/mL. Corresponding values were highly different (P < .001) and averaged 57.4 mm Hg, 7.311, 31.6 mg/dL, 5.0 ng/mL, and 24.8 ng/mL in the control group. The HA piglets were

### Table 4. Birth weight, viability, and early postnatal vitality\(^a\) of highly asphyxiated\(^b\) (HA) piglets at birth

<table>
<thead>
<tr>
<th>Item</th>
<th>Birth wt, g</th>
<th>% of highly viable piglets(^c)</th>
<th>Time to reach the udder, min</th>
<th>Rectal temperature at 24 h, °C</th>
<th>Mortality over 10 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA piglets ((n = 14))</td>
<td>1,051 ± 83(^d)</td>
<td>36.0%</td>
<td>63 ± 18</td>
<td>36.3 ± .9</td>
<td>6/14</td>
</tr>
<tr>
<td>Control piglets ((n = 67))</td>
<td>1,313 ± 41</td>
<td>79.4%</td>
<td>32 ± 4</td>
<td>38.4 ± .1</td>
<td>13/67</td>
</tr>
</tbody>
</table>

\(^a\)Early postnatal vitality was evaluated from rectal temperature at 24 h, the time to reach the udder, and survival rate over 10 d, as described in Materials and Methods.

\(^b\)Piglets assigned to the HA group met the following criteria: pCO2 > 70 mm Hg, pH < 7.1, and blood lactate > 60 mg/dL. Average values were as follow: pCO2 = 88.4, pH = 7.002, lactate = 64.6 mg/dL, plasma epinephrine = 44.5 ng/mL, and plasma norepinephrine = 237.5 ng/mL \((n = 14)\). These values showed that piglets suffered from acute asphyxia during parturition.

\(^c\)Piglets belonging to the high viability group: viability at birth was assigned as described in Materials and Methods.

\(^d\)Values are means ± SE. Means were compared by Student’s t test.

\(^e\)Difference in mortality rate was tested by chi-square analysis (FREQ procedure of SAS, 1988).
Table 5. Birth weight, blood and plasma measurements at birth, and early postnatal vitality of piglets dying before 10 d of age

<table>
<thead>
<tr>
<th>Item</th>
<th>pCO₂ mm Hg</th>
<th>pH</th>
<th>Blood lactate, mg/dL</th>
<th>Hemoglobin, g/dL</th>
<th>Epinephrine, ng/mL</th>
<th>Norepinephrine, ng/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-piglets^c</td>
<td>66.5 ± 4.3</td>
<td>7.205 ± .036</td>
<td>48.9 ± 5.2</td>
<td>9.4 ± 3</td>
<td>15.9 ± 5.5</td>
<td>72.8 ± 24.2</td>
</tr>
<tr>
<td>C-piglets</td>
<td>61.6 ± 1.9</td>
<td>7.274 ± .017</td>
<td>32.2 ± 2.3</td>
<td>10.1 ± 2</td>
<td>9.8 ± 2.8</td>
<td>42.0 ± 12.0</td>
</tr>
<tr>
<td>(59)</td>
<td>(59)</td>
<td>(76)</td>
<td>(70)</td>
<td>(57)</td>
<td>(75)</td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>NS</td>
<td>.05</td>
<td>.01</td>
<td>.05</td>
<td>NS</td>
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</table>

Birth wt and postnatal vitality

<table>
<thead>
<tr>
<th>Item</th>
<th>Birth wt, g</th>
<th>Time to reach the udder, min</th>
<th>Rectal temperature at 24 h, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-piglets</td>
<td>1,064 ± 63</td>
<td>55 ± 12</td>
<td>36.5 ± .8</td>
</tr>
<tr>
<td>(25)</td>
<td>(24)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>C-piglets</td>
<td>1,342 ± 33</td>
<td>23 ± 3</td>
<td>38.6 ± .1</td>
</tr>
<tr>
<td>(82)</td>
<td>(67)</td>
<td>(84)</td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
</tr>
</tbody>
</table>

^aEarly postnatal vitality was evaluated from rectal temperature at 24 h, and the time to reach the udder as described in Materials and Methods.

Forty-three percent of these piglets died before 10 d of age, which is much higher than the 19.4% mortality for the control group (P < .06).

We have summarized (Table 5) the general characteristics of the liveborn piglets dying before 10 d (D-piglets, n = 25) and compared them with those of the 84 piglets that were still alive at 10 d of age (C-piglets). The D-piglets suffered from a higher degree of neonatal asphyxia (lower blood pH, P < .05, and higher blood lactate, P < .01), had lower levels of hemoglobin (P < .05), and were lighter at birth (P < .01). In addition, they took a longer time to find the udder (P < .01) and exhibited a much lower RT₄₈ (P < .01) than C-piglets. Finally, 64% of these piglets were presented posteriorly (vs 44% for C-piglets), and 89% were born in the middle and last third of farrowing.

Discussion

Present results confirm that piglets suffering from asphyxia during delivery are less viable at the time of birth and indicate that neonatal asphyxia reduces early postnatal vitality through the extension of the time taken to find the udder and the lowering of the ability to maintain body temperature at 1 d of age. This results in the lowering of postnatal growth rate and neonatal survival over the first 10 d of life.

Variables Related to the Progress of Parturition and the Degree of Neonatal Asphyxia. Asphyxia during delivery causes decreased blood pH, increased blood pCO₂ and lactate, and decreased blood pO₂, and has been repeatedly reported as a main cause of noninfectious intrapartum stillbirth in pigs (Randall, 1971, 1972a,b, 1989; Sprecher et al., 1974; Zaleski and Hacker, 1993a). Our results confirm that cord blood pCO₂, pH, and lactate concentrations are excellent indices of the degree of asphyxia suffered by piglets during delivery. They clearly show that neonatal asphyxia is common, of great variability in pigs, and associated with the production of unusually high levels of the stress hormones epinephrine, and norepinephrine, which could play a crucial role in the protection of the fetus during oxygen deprivation (Lagercrantz and Slotkin, 1986). In agreement with the studies related to the occurrence of stillbirth, our results show that the extent of neonatal asphyxia increases with increasing duration of farrowing, litter size, and late position in the birth order. This is probably related to the cumulative effects of successive contractions in reducing the oxygenation of the unborn piglets and to the greater risk of detachment of the placenta as delivery progresses (English and Wilkinson, 1982). Zaleski and Hacker (1993a) also reported that a broken umbilical cord was related to a low viability score at birth, but in our study liveborn piglets show no sign of umbilical cord damage. In addition, one point that was not noticed by others is the striking effect of the presentation of the piglet. Posterior presentation was recorded for 52% of the piglets and was associated with a greater degree of asphyxiation and a greater risk of postnatal mortality, because 64% of the piglets dying before 10 d of age...
were born posteriorly. The incidence of this measurement on neonatal asphyxia needs further investigation, because it has also been shown that the proportion of posterior presentations increased in the later stages of parturition (Randall, 1972a). Finally, and surprisingly enough, piglet birth weight was inversely related to the degree of asphyxia, i.e., blood lactate level at birth, and HA piglets were 20% lighter and less viable than control piglets. Together with previous results showing that piglet birth weight was related to viability score (Zaleski and Hacker, 1993a), this suggests that, although delivery is assumed to be less distressing for the small piglets, they are more likely to experience neonatal asphyxia, which can have mid-term effects on postnatal vitality and survival rate.

**Neonatal Asphyxia Reduced Viability at Birth.** As previously reported by Randall (1971) and Zaleski and Hacker (1993b), viability at birth is inversely related to the degree of neonatal asphyxia and decreases in the middle and last third of farrowing. Highly viable piglets are also more prone to adapt to extrauterine life because they find the udder rapidly and are already able to maintain homeothermia at 1 d of age. Indeed, piglets of low viability die during the first 10 d of life, which confirms that the viability score is highly correlated with survival of piglets to 10 d of age (De Roth and Downie, 1976).

Additional information on viability and metabolic state of the piglets is available through the analysis of plasma glucose concentrations. Asphyxia initially increased plasma glucose concentrations, which reach a plateau in highly asphyxiated animals. Plasma glucose concentrations at birth were higher in the less viable piglets, the highly asphyxiated piglets, and the piglets dying before 10 d of age than in respective control animals. Higher blood glucose concentrations have also been reported in stillborn and weakborn piglets (Svendsen et al., 1986; Lauterbach et al., 1987), in piglets born during the latter stages of farrowing (Stanton et al., 1973), and in neonatal rats (Jansen et al., 1984) and calves (Edwards and Silver, 1969) during temporary asphyxia at birth. The pronounced rise in plasma glucose during neonatal asphyxia could be primarily caused by the huge release of catecholamines and associated stimulation of liver glycogenolysis (Randall, 1979). In fact, we found a significant relation between circulating concentrations of glucose and epinephrine. However, a limitation of glucose utilization by peripheral tissues cannot be excluded, because insulin secretion and glucose uptake are reduced during hypoxia (Mann, 1970; Bloom et al., 1976). Whatever the cause, blood glucose concentrations at birth are usually very low, close to 0.5 g/L, and it must be pointed out that higher than normal glucose concentrations are not optimistic indicators of the ability of piglets to adapt to extrauterine life but, on the contrary, reflect the degree of asphyxia suffered by the animal during delivery.

**Neonatal Asphyxia Reduced Early Postnatal Vitality and Survival.** More generally, the main feature of this work is the demonstration that neonatal asphyxia can have mid-term effects on early postnatal vitality and survival, as suggested previously by Randall (1971), Stanton et al. (1973) and English and Wilkinson (1982). Neonatal asphyxia delays the first contact with the udder and the first intake of colostrum and is associated with a reduction of rectal temperature at 24 h of life, growth rate, and survival over 10 d, these criteria being of prognostic value for early postnatal vitality (Hoy et al., 1995a,b). Postnatal vitality is also positively correlated with birth weight, as shown by Hoy et al. (1994), but the effect of asphyxia was often as high as, and sometimes higher than, the effect of birth weight.

The sequence of events leading to reduced vitality and, ultimately, to piglet mortality is only hypothetic. Intrapartum anoxia may interfere with lung expansion and subsequent gas exchange (Stanton and Carroll, 1974), causing respiratory distress and possibly long-term effects on the regulation of breathing (Okubo and Mortola, 1988). In addition, we have shown that intrapartum asphyxia tremendously activates the sympathoadrenal system, and the liberated catecholamines may elicit several deleterious actions such as damage to brain capillary endothelium and acidosis, possibly associated with the mobilization of carbohydrates stores in anaerobic conditions. Depletion of glycogen stores will also reduce the physiological reserves of the newborn and its ability to withstand prolonged bouts of extra-uterine stress. This may lead to reduced vigor at birth, less aggressive nursing behavior, and, consequently, reduced colostrum intake, thereby enhancing the shortening of energy supply for thermoregulation. This is confirmed by the dose link observed in this study among degree of asphyxia, time taken by the piglet to find the udder, and rectal temperature at 24 h. In addition, this strengthens the conclusion that an early intake of an adequate amount of colostrum is necessary for postnatal development of thermoregulation. But direct effects of neonatal asphyxia on thermoregulatory abilities cannot be excluded, as suggested in neonatal rats (Mortola and Dotta, 1992) and lambs (Alexander and Williams, 1970; Eales and Small, 1985) during experimentally induced hypoxia. Overall, intrapartum anoxia, acidemia, and hypercapnia may lead to the depression of brain thermoregulatory centers and hypothalamic heat-regulating mechanisms, thereby increasing the cold susceptibility of newborn pigs. In addition, shivering thermogenesis is known to be altered during severe hypoxia (Hemingway and Biritzis, 1956). Most of these alterations of thermogenic capacities, however, were observed during and not after the hypoxic episode.
Implications

Birth asphyxia clearly interacts with piglet behavior and postnatal development of thermoregulation, delaying the first intake of colostrum and reducing body temperature at 24 h of life. One can calculate that asphyxia during delivery is directly responsible for the mortality of at least 5.5% (6/110) of the liveborn piglets, which represents 24% (6/25) of early postnatal mortality. Baby pig survival could probably be substantially increased through the reduction of the extent and/or consequences of birth asphyxia. This means that in modern housing conditions and with an always increasing number of piglets born per litter, management practices such as 1) induction, supervision, and control of duration of farrowing, 2) assistance to weak piglets and piglets that are particularly at risk, i.e., later born piglets, lower weight piglets, and piglets born posteriorly, in establishing respiration, 3) provision of an early intake of colostrum through tube feeding or help to reach the udder, and 4) provision of an adequate ambient temperature in the farrowing crate through progressive shift of heating lamps from the back to the side of the sow, should help to save more piglets. Alternatively, the possibility of improving postnatal survival through oxygen inhalation of asphyxiated neonates early after birth needs to be investigated.

Literature Cited
