Neurophysiological development of newborn pigs: effect of the sow's parity number in eutocic farrowings

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Abstract

The objective of the present study was to determine the effect of sow parity on neonatal piglet health and vitality at birth. We evaluated 1505 neonate piglets, which were born of York-Landrace sows with the following parity distribution: primiparous (n = 202), second (n = 207), third (n = 211), fourth (n = 222), fifth (n = 225), sixth (n = 218) and seventh parity (*n* = 220). Piglets born to primiparous and seventh-parity sows had the lowest and highest birthweights respectively, and showed the most marked imbalances in blood gas exchanges, acid-base balance and energy profiles, as well as the highest percentage of severe meconium staining of the skin and the lowest vitality scores ($P < 0.05$). In contrast, the neonates from the fourth-parity sows had the highest vitality scores, required less time to reach the mother's teat, and had the highest percentage of adhered umbilical cords and newborns with dyspnoea, apnoea and abnormal heartbeat ($P < 0.05$). The results of this study suggest that during eutocic farrowings, the sow's parity number has the following effects on newborn piglets: reduced vigour and longer latencies to begin breathing, stand and take the teat. These effects are due to the presence of imbalances in gas exchanges, the acid-base balance and energy profiles that occurred when the mother was a primiparous or older sow. These signs indicate that the newborn piglet survived a process of intrapartum asphyxia.

Introduction

It is currently believed that the sow's parity number (and sow's age) is closely related to processes of neonatal hypoxia (Olmos- Hernandez *et al.* 2008; Mota-Rojas *et al.* 2012a, 2012b; Muns *et al.* 2013). Also, some authors postulate that the neonatal period is the most critical stage in the production cycle of farm animals, ~14% of all live-born pigs have low postnatal viability due to decreased fetal blood flow and oxygen during birth (Mota-Rojas *et al.* 2002,2007; Rootwelt *et al.* 2013). Forthese reasons, various studies have been conducted to determine the principle causes of perinatal hypoxia (Mota-Rojas *et al.* 2005, 2016). Maternal factors associated with neonatal hypoxia include the duration of labour, placental blood flow and stress, be that environmental (such as heat stress) or stemming from altered health or endocrine status that may reduce oxygenation (Alonso-Spilsbury *et al*. 2005; Mota-Rojas *et al.* 2006; Orozco-Gregorio *et al.* 2008, 2010). Another risk factor for intrapartum hypoxia is the birthweight of the neonate, as newborns with low birthweights are more likely to suffer oxygen restriction and the secondary effects of hypoxemia (Herpin *et al.* 1996; Marchant *et al.* 2000; Orozco-Gregorio *et al.* 2008, 2010). With similar objectives in mind, other studies have determined that assessing neonatal vitality is a valid clinical approach to the study of the neurofunctional status of newborns and short-term survival in piglets, as low scores could be indirect indicators of intrapartum asphyxia (Mota-

Rojas *et al*. 2005, 2006; Gonzalez-Lozano *et al*. 2009a; Orozco-Gregorio *et al.* 2011). Other important factors that predispose neonatal piglets to hypoxia are birth order, more extensive meconium staining, laceration or rupture of the umbilical cord by effects of successive contractions, prolonged farrowing and dystocia (Martinez-Rodriguez *et al.* 2011; Mota- Rojas *et al.* 2012a; Rootwelt *et al.* 2013). Analysing these alterations has made it possible to determine the severity of asphyxia in neonate piglets (van Dijk *et al.* 2006; Trujillo *et al.* 2011), puppies (Crissiuma *et al.* 2010), colts (Castagnetti *et al.* 2010) and humans (Low *et al.* 1994; da Silva *et al.* 2000). Furthermore, these analyses have provided useful information that has improved our understanding of the neurophysiological status of newborns (Nodwell *et al.* 2005; Orozco-Gregorio *et al.* 2008; Mota-Rojas *et al.* 2016). Various studies have determined the main causes of neonatal hypoxia in piglets, but without exploring how the age and parity of the sow affect the physiological and metabolic profiles and survival of newborn piglets, while setting aside the problematic cases of dystocia. Therefore, the objective of the present study was to comprehensively evaluate the effect of the sow's parity number on the key biological parameters of neonatal pigs in eutocic farrowings, including birthweight, morphology of the umbilical cord, degree of meconium staining of the skin, vitality scores, gas exchanges, acid-base balance and blood energy profiles.

Materials and methods

Ethics

The experimental protocol of the study was approved by the Doctoral Commission of Biological Sciences at the Universidad Autonoma Metropolitana Iztapalapa-Xochimilco in Mexico City, Mexico, in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). All work was conducted in accordance with the guidelines for the ethical use of animals in applied ethological studies, described by Sherwin *et al.* (2003). Research was conducted on a commercial pig farm in central Mexico with ~1250 sows. Telephones, televisions and other sources of noise were not allowed in the production and farrowing areas to decrease potential sources of stress.

Animals and housing conditions

A total of 105 York-Landrace sows (first to seventh parity) and their litters (1505 piglets) were included. Fifteen sows of each farrowing were used, and the distribution of the piglets by parity number was as follows: first (n = 202 piglets), second (n = 207 piglets), third (n = 211 piglets), fourth (n = 222 piglets), fifth (n = 225 piglets), sixth (n = 218 piglets) and seventh (n = 220 piglets). The parameters evaluated were: neurological function, vitality score, blood gas exchanges, acid-base equilibrium and energy balance. The day of insemination was considered day 1 of gestation. Throughout gestation, all sows were housed in individual stalls (3.7 m^2) with plasticised slatted-floors and water available *ad libitum.* Sows were fed 2.5-3.0 kg/day of a corn-soybean gestation diet that provided 14% crude protein, 0.70% lysine, 4.0% crude fibre and 14 MJ ME/, sufficient to meet or exceed their nutritional requirements. This remained unchanged throughout pregnancy up to the 4th day before the expected farrowing. Afterwards, the sows were fed a corn- soybean lactation diet (1.25% Lys, 5.0% crude fibre and 20% CP) up to postpartum day 21. On day 109 of gestation, the sows were moved to a climate-controlled (27°C, 60% relative humidity) farrowing room and housed in individual farrowing crates with the following dimensions: 1.45-m long x 0.8-m wide x 0.57-m high. Sows and piglets had *ad libitum* access to water in separate nipple drinkers. Farrowing time was induced by an intramuscular injection of prostaglandins (dinoprost trometamin; Lutalyse® Pharmacia Animal Health and Upjohn, Inc., New York, NY, USA; 10 mg of prostaglandin analogue IM) administered 36 h before the expected farrowing date on day 114 of gestation.

Treatment

To avoid interference with our measurements, no birth management or assistance was offered to the sows or piglets during farrowing or at birth. The exclusion criteria applied included: sows that required obstetric handling due to a delay longer than 90 min between the expulsion of piglets, sows with duration of expulsion >200 min and sows that required an application of oxytocin before contractions ended. Extremely nervous or obese sows with >28 mm of back fat at farrowing (determined by ultrasound Renco Preg-Alert, Minneapolis, MN, USA) were excluded from electronic uterus monitoring in accordance with the methodology outlined by Gonzalez- Lozano *et al.* (2009b). In addition, distocic sows that had uterine contractions >30 mm/Hg, compared with 30 mm/Hg for eutocic sows, and showed uterine atony for at least 40 min were excluded; according to

Gonzalez-Lozano *et al.* (2010), maternal-fetal dystocia is considered when at least one of the first four piglets expelled is an intrapartum stillbirth.

Measurements

Electronic uterus monitoring

Electronic uterus monitoring covered the time from expulsion of the first piglet to the birth of the last one, and included all sows. Prior to farrowing, the uterus transducer was placed on the sow's abdomen with abundant obstetric gel (Farmaceuticos Altamirano de Mexico SA de CV, Mexico City, Mexico). Electronic uterus monitoring was carried out using an electronic digital cardiotocograph (Fetal Monitor Medical Systems, Inc., Wallingford, CT, USA). Patterns of uterine contractions were recorded on thermal paper according to the information processed by the transducer, where every centimetre measured by the device represented a 1-min record. Electronic uterus monitoring included uterus activity, and the number, duration, interval and frequency of contractions, following a methodology used previously by other authors (Trujillo *et al*. 2007; Orozco-Gregorio *etal.* 2008; Gonzalez-Lozano *etal.* 2009b; Mota-Rojas *et al.* 2011). Additionally, duration of farrowing was registered as the time elapsed (min) from the rupture of the amniotic membrane to the expulsion of the placenta.

Physiological and metabolic profiles

In order to assess acid-base balance and gas exchange, all blood samples of the neonates were gently collected by a trained researcher. Blood was taken immediately after the expulsion of each piglet that presented regular respiratory movements. The average sampling time was <20 s. Sampling was performed by retro-orbital bleeding with a 100-µL microcapillary tube in the medial canthus of the eye at a 30-45° angle towards the back of the eye. The tube was inserted into the venous suborbital sinus, following the technique described by Orozco-Gregorio *et al.* (2008). All blood samples were placed in glass tubes containing lithium heparin. Blood pH, glucose (mg/dL), electrolytes (Na^+, K+ and Ca^{2+} (mEq/L)), bicarbonate (HCO_3^-) and lactate (mg/dL) levels, and partial carbon dioxide (pCO2 (mm Hg)) and oxygen pressure (pO2 (mm Hg)) were measured with a blood gas and electrolyte analyser (GEM Premier 3000; Instrumentation Laboratory Co., Lexington, MA, USA; Instrumentation Laboratory SpA, Milano, Italy). All personnel involved in the sampling procedure had received prior instruction and training.

Vitality assessment

Immediately after the blood samples were obtained, a viability score for each piglet was calculated according to the scale described by Zaleski and Hacker (1993), and modified by Mota-Rojas *et al.* (2005). The following variables were scored individually on a scale from 0-2: (1) heart rate (<110, 121-160 or >161 beats/min), (2) the time interval from birth to first breath (>1 min, 16 s-1 min, or <15 s), (3) snout skin colour (pale, cyanotic or pink), (4) the interval from birth to first standing (>5 min, 1-5 min or <1 min), and (5) meconium staining of the skin (severe, mild or absent). The time to first breath was recorded as the time interval between birth and the moment when thoracic movements were visible and air exhalation from the snout was noted. The degree of meconium staining of the skin was also evaluated. This parameter was considered severe (2) when >50% of the body surface was stained; moderate (1) when <50% was stained; and absent (0) when there was no visible staining. The scores of the 5 variables were aggregated to obtain a viability score between 0-10. It is important to mention that heart rate was not measured until the neonates were capable of maintaining a standing posture. Additionally, the time required to connect to the teat was recorded. As the piglets were removed from their pens to draw the blood samples for the purposes of this study, the time recorded for the piglet to stand up and the time when it made first contact with the teat were both determined after they were returned to their dams.

Umbilical cord integrity was evaluated at birth and classified as adhered (normal) or broken, using the criteria described by Mota-Rojas *et al.* (2002). Immediately after assessing the umbilical cord, piglets were individually weighed in a digital bascule (Salter Weight-Tronix Ltd, West Bromwich, UK), and their temperature was taken using a tympanic membrane thermometer (ThermoScan Braun GMBH, Kronberg, Germany). Neonates were considered motionless when they made no attempt to stand within 5 min after expulsion.

Evaluations of vitality and physiological performance were conducted by two researchers with experience in handling newborn piglets. Finally, all the procedures performed with each piglet were completed in an average time of 5 min.

Statistical analyses

All statistical analyses were carried out using JMP 8.0 (JMP Institute, Marlow, Buckinghamshire, UK). All data were explored to determine distributions using the JMP univariate procedure. To study the effect of the sow's parity number on the parametric variables analysed (i.e. blood metabolites, temperature, birthweight, vitality scale, latency to standing, latency to take the teat), an analysis of variance was performed using general linear models. In these models, the sow' s parity number was included as the main effect, birthweight and duration of parturition were introduced as the covariates to be considered in the model for temperature, vitality, attempts to stand and latency to take the teat. When significant differences were found, a Tukey multiple comparison of means test was conducted. As blood pH is a logarithmic scale, the endpoint was analysed with a Kruskal-Wallis test ($P < 0.05$). To study the effect of the sow's parity number on the non-parametric variables, the Chi-squared test (for number of motionless neonates, number of newborn piglets with dyspnoea, meconium staining of the skin and umbilical cord integrity) was conducted ($P < 0.05$), followed by the Fisher's exact test to locate differences. In addition, a linear regression analysis was carried out for the groups of neonates from the gilts and seventh-parity sows. The sex was not included in statistical analyses. The significance level was set for two tails in all cases ($P < 0.05$). The researchers who performed the assessment and collected the study outcomes were not aware of the treatments and did not participate in selecting the animals or data analysis.

Results

All the piglets showed changes in vitality, neurofunctional performance, gas exchanges, acid-base balance, mineral balance and energy profiles. The newborn piglets in the seventh parity group showed significant changes in vitality, neurofunctional performance, gas exchange, acid-base balance, mineral balance and energy profiles compared with the piglets of the other parities ($P < 0.05$). The neonates born to the second, third, fifth and sixth-parity sows had a tendency toward imbalances in glucose, lactate and calcium, but the newborns born to the gilts and the seventh-parity sows showed the largest imbalances for all variables. Piglets from the fourth-parity sows had the lowest indexes of neurophysiological imbalances *(P < 0.05)*. The neonates born to the seventh-parity sows showed a mean decrease of 0.5°C in body temperature compared with the other groups *(P < 0.05)*. In addition, this group had the highest average birthweight, at 1682.45 ± 11.95 g, which exceeded the mean birthweights of all other groups (P < 0.05) (Table 1). With regard to neonate performance, there were significant differences in vitality scores and neurofunctional performance at the time of birth among the different parity groups (P < 0.05). However, there was no sex effect on the blood physiological, metabolic variables and vitality scores in relation to parity number (P > 0.05).

Acid-base balance

Piglets born to gilts and seventh-parity sows had the lowest pO2 (18.1 ± 0.27 and 17.75 ± 0.26 mmHg respectively) compared with fourth-parity sows (27.79 ± 039; P < 0.05). In contrast, piglets from the third-, fourth- and fifth-parity sows presented an increase in pO2 that averaged 8.95 mmHg above that of the newborns from the gilts and sixth-parity sows (P < 0.05). With regard to pCO2, the piglets born to the gilts and seventh-parity sows showed an increase (P < 0.05) of 47 mmHg above the neonates of the second-, third-, fourth-, fifth- and sixth-parity groups. However, the neonates from the fourth-parity sows had the lowest pCO2 concentration (44.0 ± 0.73 mmHg) of all groups (P < 0.05) (Table 2). The blood pH values of the piglets from the fourth- (7.33 ± 0.009), fifth- (7.27 ± 0.02) and sixth-parity sows (7.26 ± 0.02) were higher (P < 0.05) than those of the neonates born to the gilts (7.10 ± 0.01) and the second- (7.16 ± 0.009), third- (7.22 ± 0.02) and seventh-parity sows (7.04 ± 0.006), but the neonates from the latter had the lowest blood pH values of all groups (P < 0.05). Blood HCO3- levels were lower in neonates from the sixth- and seventh-parity sows by a mean of 3.5 mmol/L compared with the levels observed in neonates from the gilts and the third-, fourth- and fifth-parity sows (P < 0.05). Finally, the piglets from the seventh-parity sows had the lowest blood bicarbonate levels (16.80 ± 0.21 mmol/L) of all groups (P < 0.05; Table 2). In the linear regression analysis, the variables pCO2 and pO2 were significantly correlated with the variables Ca^{2+} and pH in the neonates born to the gilts and seventh-parity sows ($P < 0.05$). For the neonates born to the gilts (Table 3), pO_2 concentrations were inversely related to pCO_2 ($r = -0.245$) and glucose concentrations ($r = -0.138$), but directly related to Ca^{2+} concentrations ($r = 0.426$) and pH ($r = 0.162$). For the neonates in the seventh-parity group (Table 4), pCO_2 concentrations were inversely correlated with pO_2 concentrations ($r = -0.25$) and pH ($r = -0.238$).

Gas exchange

Data revealed a pO_2 decrease ($P < 0.05$) in the piglets born to gilts (18.11 ± 0.27 mmHg) and the seventh-parity sows (17.75 ± 0.26 mmHg), compared with fourth-parity sows ($P < 0.05$). In contrast, piglets from the third-, fourth- and fifth-parity sows presented an increase in pO_2 that averaged 8.95 mmHg above that of the newborns from the gilts and sixth-parity sows ($P < 0.05$; Fig. 1). With regard to pCO_2, piglets born to gilts and seventh- parity sows showed an increase ($P < 0.05$) of 47 mmHg above the neonates of the second-, third-, fourth-, fifth- and sixth-parity groups. However, the neonates from the fourth-parity sows had the lowest pCO_2 concentration (44.0 ± 0.73 mmHg) than all other groups ($P < 0.05$) (Table 2).

Energy metabolism

Energy metabolism showed an increase of 26.91 mg/dL in the blood glucose levels of the piglets born to the seventh-parity sows compared with the blood values for all groups of neonate piglets ($P < 0.05$). Blood lactate levels, meanwhile, showed a mean increase of 34 mg/dL in the piglets born to the seventh-parity sows above those determined for all groups ($P < 0.05$). Also, the piglets born to the third- (48.56 ± 1.29 mg/dL) and fourth-parity sows (46.52 ± 1.82 mg/dL) showed blood lactate concentrations above those ($P < 0.05$) of the piglets born to the gilts and the second-, fifth-, sixth- and seventh-parity sows (Table 2).

Acid-base balance

Results obtained for acid-base balance showed that the blood pH values of the piglets from the fourth- (7.33 ± 0.009), fifth- (7.27 ± 0.02) and sixth-parity sows (7.26 ± 0.02) were higher ($P < 0.05$) than those born to gilts (7.10 ± 0.01) and second- (7.16 ± 0.009), third- (7.22 ± 0.02) and seventh-parity sows (7.04 ± 0.006). However, the neonates from the seventh parity sows had the lowest blood pH values compared with all groups ($P < 0.05$).

Blood HCO3- levels decreased in the neonates from the sixth- and seventh-parity sows by a mean of 3.5 mmol/L compared with the levels observed in neonates from gilts and third-, fourth- and fifth- parity sows (P < 0.05). Finally, piglets from the seventh-parity sows had the lowest blood bicarbonate levels (16.80 ± 0.21 mmol/L) among all groups (P < 0.05) (Table 2).

Mineral balance

This study found an increase (P < 0.05) in Ca^{2}+ concentrations in the piglets born to the gilts and seventh-parity sows (1.97 ± 0.008 mmol/L, respectively, above the levels for the other groups). Blood K+ concentrations in the neonates born to the gilts (6.22 ± 0.04 mmol/L) and seventh-parity sows (6.23 ± 0.03 mmol/L) were significantly lower (P < 0.05) compared with the other groups of piglets (Table 2).

Neurophysiological performance

The neonates born to the seventh-parity sows showed a mean decrease of 0.5°C in body temperature compared with the other groups (P < 0.05). In addition, this group also had the higher average birthweight of 1682.45 ± 11.95 gandexceeded the mean birthweights of all other groups (P < 0.05). Table 1 shows the effect of the sow's parity number on the neurophysiological parameters measured. The parameters presented include the vitality scale, latency to reach the teat, birthweight and body temperature (Table 1).

In terms of the vitality scale, piglets born to gilts (6.27 ± 0.11) and the seventh-parity sows (6.4 ± 0.07) achieved lower scores than those of second-, third-, fourth-, fifth- and sixth-parity sows (P < 0.05); whereas the newborns from the fourth-parity sows (8.28 ± 0.07) showed the highest scores (P < 0.05) of all parity groups. Regarding latency to reach the teat, the study revealed that neonatesbornto gilts and (54.55 ± 0.98 min) seventh-parity sows (48.85 ± 0.57min)tookonan average 21.1s more to reach the teat and begin suckling than piglets born to the second-, third-, fourth-, fifth- and sixth-parity sows (P < 0.05). The piglets born to the fourth-parity sows (23.9 ± 0.53 min) required the lowest time to connect to the mother's teat (P < 0.05).

Meconium staining and umbilical cord morphology

The piglets born to the gilts and seventh-parity sows had the highest percentages of severe meconium staining

(9.9% and 10.45%, respectively) compared with the other groups (P < 0.05). The neonates born to the fourth-parity sows had the highest percentage of adhered umbilical cords (98.2%) compared with all groups. In contrast, the piglets born to the seven-parity sows had the highest percentage of broken umbilical cords (14.09%) compared with all groups (Table 5).

Discussion

An important finding in this study is that the neonates born to primiparous and seventh-parity sows in eutocic farrowings suffered the most pronounced alterations of their vitality, physiological and metabolic profiles. The association of these alterations in the piglets with the sow's parity indicates the existence of different factors inherent in the neonates that could influence their individual performance during the birthing process. In contrast, the physiological changes that the piglets experience at the moment of birth, including increased blood pCO_2, lactate and Ca^2+ levels, together with the low levels of pH, pO2 and K+, may indicate a higher level of intrapartum hypoxia (Ferriero 2004); however, these alterations of some aspects of the acid-base balance (glucose, lactate, pH, pCO_2), as asphyxia indicators, are much more common in newborn piglets born from dystocic farrowings (Gonzalez-Lozano *et al.* 2012), in contrast to our findings from sows with eutocic farrowings, which is why we suggest that the peripartum period can be especially stressful for gilts because of the new environment, the farrowing process itself (Tummaruk *et al*. 2010; Baxter *et al.* 2012; Muns *et al.* 2014). In addition, the narrowness of the gilt's pelvis and the stress that primiparous sows experience compared with multiparous sows could explain the high levels of hypoxia that their offspring suffered, and the increase in the number and intensity of uterine contractions, two factors that might increase the risk of intrapartum hypoxia (Olmos-Hernandez *et al.* 2008; Gonzalez- Lozano *et al.* 2009a). With respect to piglets of sows of the seventh parity, it may be that the physiological imbalances that the piglets in our study presented are more closely related to high birthweights, as this condition in neonates has been associated with respiratory imbalances in blood pCO2 and pO2 concentrations and with acid-base imbalances (Martinez- Rodriguez *et al.* 2011). These conditions are accompanied by a decrease in the number and intensity of uterine contractions (Mota-Rojas *et al.* 2015), which may complicate the process of expelling the neonates and, consequently, generate muscular fatigue in the mother. However, the findings from our study suggest that weight was more closely associated with the sows’ parity, since as each sow’ s number of parities increased, the average weight of the piglets also increased. Thus, even though the heavier piglets presented imbalances in their vitality, physiological and metabolic profiles, weight was not found to be a determining factor in those disequilibriums, as the neonates from first-parity mothers also manifested them and, moreover, some authors have associated this variable with poor thermoregulatory ability due to increased heat loss and reduced vitality, all of which affect the piglet’s ability to compete for the teat (Tummaruk and Sang-Gassanee 2013; Kirkden *et al.* 2013). In contrast, the increase in lactate levels and decrease in blood pH were identified earlier by Orozco-Gregorio *et al.* (2008), who attributed them to changes in the blood variables associated with a state of metabolic acidosis, which might reflect the severity of hypoxia at birth in piglets (van Dijk *et al.* 2008). In our study, the condition of acidosis that the piglets born to the gilts and sixth- parity mothers presented may also be associated with the long time required to connect to their mothers’ teat and lower vitality scores reported by some authors (Zaleski and Hacker 1993; Herpin *et al.* 1996; Casellas *et al.* 2004; Trujillo *et al.* 2007). Another source oflactate is anaerobic glycolysis: in the absence of oxygen, pyruvate is reduced to lactate through lactate dehydrogenase (Kaneko 1997). Therefore, the results of the present study suggest that the neonates born to the seventh- parity sows experienced more acute fetal suffering. In contrast, the piglets born to the fourth-parity sows showed the lowest imbalances of physiological and metabolic blood profiles, indicating the lowest level of intrapartum hypoxia among the parity groups. In addition, the increase in blood Ca^{2+} concentrations observed in the piglets born to the gilts and seventh-parity sows might also be the result of the process of hypoxia, because during delivery the level of muscular activity increases, thus favouring the mobilisation of calcium from the newborns’ bones (Knol *et al.* 2002; Rydhmer *et al.* 2008; Mota-Rojas *et al.* 2015), possibly as a consequence of the high muscular activity required of piglets during the expulsion process, which could be related with the incidence of broken umbilical cords, severe meconium staining and low vitality of the neonates (Mota-Rojas *et al.* 2006). It has been reported that older sows have reduced uterine muscle tone (Zaleski and Hacker 1993; Mota-Rojas *et al.* 2005; Rootwelt *et al.* 2012, 2013), which is finally reflected in the degree of meconium staining of the skin and intrauterine fetal distress (Mota-Rojas *et al.* 2002; Mota-Rojas *et al.* 2006; Trujillo *et al.* 2007; Mota- Rojas *et al.* 2016). The increase in blood glucose ascertained for the neonates from the seventh-parity sows could indicate greater neonatal distress, reflecting the piglets' efforts to compensate for the hypoxic process (Randall 1972; Gonzalez-Lozano *et al.* 2010; Mota-Rojas *et al.* 2011, 2015). The high levels of blood glucose found in the present study are similar to those reported by Herpin *et al.* (1996) and Martinez-Rodriguez *et al.* (2011), who determined glucose concentrations of 102.3 ± 6.5 mg/dL in neonate piglets with intrapartum asphyxia and high birthweight. However, Mota-Rojas *et al.* (2005) suggested that high neonatal glucose concentrations could be characteristic of a shorter period of asphyxia during which piglets succeed in conserving their energy substrates, whereas low glucose concentrations would be associated with a prolonged period of hypoxia, and greater utilisation and consumption of energy reserves. In our results, blood glucose levels could be an indicator of acute stress that may have increased due to the energy requirements that exist as a consequence of the lack of oxygenation of the fetus. This is justified by the high percentage of piglets that were born with broken umbilical cords at the moment of expulsion, coupled with apnoea, severe meconium staining, low mobility and, as a result, low scores on the vitality scale. In this regard, Herpin *et al.* (1996) mention that glucose is a good marker of neonatal distress and may reflect the capability of the piglets to compensate the process. At birth, the increments in glucose plasma levels may be explained by a release of catecholamines and stimulation of liver glycogenolysis secondary to the intrapartum asphyxia. All the findings presented above indicate that intrapartum hypoxia was intensified in the neonates born to the gilts and seventh-parity sows, reducing their vitality scores and their capacity to search for the maternal teat, despite the fact that they were products of eutocic births with no clinical evidence of the obstetric problems associated with distocic births, as can be appreciated in the present study.

Conclusions

In the present study, the parity of sows was seen to have effects on the health and vitality of newborn piglets, as the neonates born to first- and seventh-parity dams were shown to have low vitality scores reflected by the presence of severe meconium staining, cyanotic skin, and longer latencies to both stand and take the mother's teat. Those animals presented imbalances in gas exchanges, the acid-base balance and energy profiles, even in births considered eutocic. These results suggest that not only births classified as distocic affect the physiological responses of newborn piglets. Upon evaluating the parity of the sows that had eutocic births, the study was able to determine that the neonates produced by the fourth-parity dams had the fewest physiological alterations and the highest vitality scores, as they required less time to stand and connect to the teat, and had pink skin with adhered umbilical cords. Through these findings, the present study demonstrated that the alterations in the health of newborn piglets and low vitality scores due to the effects of the parity of the sow provide evidence that the newborn piglets survived a process of intrapartum asphyxia.

Conflicts of interest

The authors declare no conflicts of interest.

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Table 1. Effect of the sow's parity number on the neurophysiological parameters

a–f, Lowercase letters indicate differences among parity number groups within the blood variable ($P < 0.05$); n, number of weaned piglets sampled; s.e., standard error

Variables	Parity 1 (n = 202) Mean ± s.e.	Parity 2 (n = 207) Mean ± s.e.	Parity 3 (n = 211) Mean ± s.e.	Parity 4 (n = 222) Mean ± s.e.	Parity 5 (n = 225) Mean ± s.e.	Parity 6 (n = 218) Mean ± s.e.	Parity 7 (n = 220) Mean ± s.e.
Temperature (°C)	37.16 ± 0.03c	37.33 ± 0.04c	37.56 ± 0.04b	37.83 ± 0.04a	37.64 ± 0.04b	37.30 ± 0.04c	36.97 ± 0.02d
Birthweight (g)	1347.66 ± 19.01f	1422.2 ± 13.21ef	1427.33 ± 12.73de	1489.01 ± 17.76cd	1537.96 ± 14.79bc	1594.08 ± 17.75b	1682.45 ± 11.95a
Vitality scale	6.27 ± 0.11e	7.07 ± 0.07cd	7.32 ± 0.06c	8.28 ± 0.07a	7.79 ± 0.06b	6.9 ± 0.08d	6.4 ± 0.07e
Latency to connect to teat (min)	54.55 ± 0.98a	36.61 ± 1.05c	28.09 ± 0.68d	23.9 ± 0.53e	29.57 ± 0.92d	34.83 ± 1.18c	48.85 ± 0.57b

Table 2. Mean and standard error of the duration of parturition and physiological blood profiles of neonate piglets according to the sow's parity number

a–e, Lowercase letters in the same row indicate differences among groups within the blood variable; Tukey ($P < 0.05$); n, number of weaned piglets sampled; s.e., standard error

Blood trait	Parity 1 ($n = 202$) Mean ± s.e.	Parity 2 ($n = 207$) Mean ± s.e.	Parity 3 ($n = 211$) Mean ± s.e.	Parity 4 ($n = 222$) Mean ± s.e.	Parity 5 ($n = 225$) Mean ± s.e.	Parity 6 ($n = 218$) Mean ± s.e.	Parity 7 ($n = 220$) Mean ± s.e.
Duration of parturition (min)	184 ± 16.25a	196 ± 14.02a	167 ± 18.3a	194 ± 15.16a	185 ± 17.25a	198 ± 14.76a	187 ± 16.78a
pH	7.10 ± 0.01de	7.16 ± 0.009cd	7.22 ± 0.02bc	7.33 ± 0.009a	7.27 ± 0.02ab	7.26 ± 0.02b	7.04 ± 0.006e
Glucose (mg/dL)	99.48 ± 2.56b	72.23 ± 1.24d	79.75 ± 0.96c	80.93 ± 1.17c	75.69 ± 1.16cd	70.31 ± 0.79d	106.65 ± 2.22a
Lactate (mg/dL)	88.58 ± 1.26b	59.90 ± 1.65d	48.56 ± 1.29e	46.52 ± 1.82e	58.61 ± 1.89d	77.62 ± 1.60c	97.34 ± 0.76a
HCO_3^- (mmol/L)	20.45 ± 0.16cd	21.05 ± 0.16c	22.22 ± 0.15b	23.30 ± 0.18a	22.42 ± 0.19b	19.88 ± 0.22d	16.80 ± 0.21e
Ca^{2+} (mmol/L)	1.97 ± 0.008a	1.69 ± 0.008b	1.64 ± 0.01c	1.56 ± 0.01d	1.61 ± 0.01c	1.62 ± 0.008c	1.97 ± 0.008a
Na^+ (mmol/L)	135.20 ± 0.20ab	134.96 ± 0.23b	135.24 ± 0.25ab	136.05 ± 0.24a	135.78 ± 0.25ab	135.69 ± 0.26ab	135.06 ± 0.18b
K^+ (mmol/L)	6.22 ± 0.04b	6.60 ± 0.03a	6.72 ± 0.04a	6.64 ± 0.03a	6.59 ± 0.03a	6.61 ± 0.04a	6.23 ± 0.03b

Table 3. Correlations of the physiological and metabolic blood variables of the neonate piglets born to the gilts

The independent variables were numbered according to the correlation coefficient (R-value). The final *F*- andP-values observed in this table are from the analysis of variance of the linear regression analyses (y = b + mx). The parameter in the linear equation is shown in relation to the corresponding mean standard error

Dependent variable (y)	Independent variable (x)	B	s.e.	*R*	R^2	*F*-value	*P*-value
pO_2 (mmHg)	pCO_2 (mmHg)	-0.073	0.02	-0.245	0.06	12.812	<0.0001
	Lactate (mg/dL)	-0.028	0.015	-0.129	0.017	3.381	0.067
	HCO_3^- (mmol/L)	0.022	0.117	0.013	0.0001	0.36	0.85
	Ca^{2+} (mmol/L)	0.199	0.03	0.426	0.182	44.371	<0.0001
	Glucose (mg/dL)	-0.015	0.008	-0.138	0.019	3.862	0.051
	pH	4.373	1.886	0.162	0.026	5.376	0.021

Table 4. Correlations ofthe physiological and metabolic bloodvariables ofthe neonate piglets born to the seventh-parity sows

The independent variables were numbered according to the correlation coefficient (R-value). The final F- and P-value observed in this table are from the analysis of variance of the linear regression analyses (y = b + mx). The parameter in the linear equation is shown in relation to the corresponding mean standard error

Dependent variable (y)	Independent variable (x)	B	s.e.	*R*	R^2	*F*-value	*P*-value
pCO_2 (mmHg)	pO2 (mmHg)	-0.844	0.221	-0.25	0.063	14.56	<0.0001
	Lactate (mg/dL)	0.015	0.08	0.012	0.0001	0.034	0.855
	$HCO3^-$ (mmol/L)	-0.263	0.277	-0.64	0.004	0.903	0.343
	Ca^2+ (mmol/L)	20.9	6.614	0.209	0.044	9.99	0.002
	Glucose (mg/dL)	0.03	0.027	0.074	0.005	1.201	0.274
	pH	-30.461	8.423	-0.238	0.057	13.079	<0.0001

Table 5. Assessment of the performance at birth of neonate piglets due to the effect of the sow's parity number

Pearson's Chi-squared test (P < 0.05)

Variables	Parity 1 (n = 202) *n* (%)	Parity 2 (n = 207) *n* (%)	Parity 3 (n = 211) *n* (%)	Parity 4 (*n* = 222) *n* (%)	Parity 5 (*n* = 225) *n* (%)	Parity 6 (n = 218) *n* (%)	Parity 7 (*n* = 220) *n* (%)	Prob > ChiSq *P*
Neonates with adhered umbilical cord	178 (88.11)	191 (92.27)	196 (92.89)	218 (98.2)	210 (93.33)	192 (88.07)	189 (85.91)	<0.05
Neonates with broken umbilical cord	24 (11.88)	14 (6.76)	16(7.58)	4(1.8)	15 (6.67)	26 (11.93)	31 (14.09)	<0.05
Neonates motionless	16 (7.92)	2(1.93)	6 (2.84)	1 (0.45)	7 (3.11)	20 (9.17)	22 (10.0)	<0.05
Neonates with dyspnoea	12 (5.94)	6 (2.89)	3 (1.42)	1 (0.45)	3 (1.33)	10 (4.58)	17 (7.72)	<0.05
Neonates with severe meconium staining	20 (9.90)	10 (4.83)	5 (2.36)	2 (0.90)	7 (3.11)	17 (7.79)	23 (10.45)	<0.05
Neonates with apnoea and heart beat	7 (3.46)	3 (1.44)	2 (0.94)	1 (0.45)	3 (1.33)	6 (2.75)	9 (4.09)	<0.05

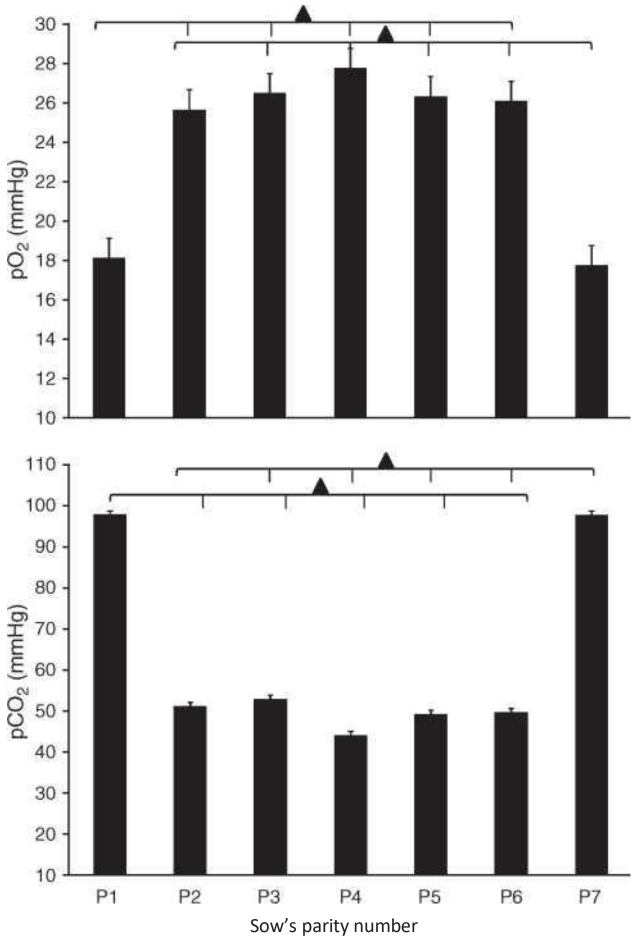

Fig. 1. Assessment of gas exchange in neonate piglets due to the effect of the sow's parity number (mean ± s.e.). Differences among groups within the blood variable (▲; *P* < 0.05; ANOVA followed by Tukey's*post hoc* test). (a) Partial oxygen pressure. *(b)* Partial carbon dioxide pressure.