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To cite this article: A.L Soraci , J.M Decundo , S.N Dieguez , G Martinez , A Romanelli , D.S Perez Gaudio , M.B Fernandez Paggi & F.A Amanto (2020): Practical oxygen therapy for newborn piglets, New Zealand Veterinary Journal, DOI: [10.1080/00480169.2020.1778580](https://doi.org/10.1080/00480169.2020.1778580)

To link to this article: <https://doi.org/10.1080/00480169.2020.1778580>



Accepted author version posted online: 18 Jun 2020.



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Publisher: Taylor & Francis & New Zealand Veterinary Association

Journal: *New Zealand Veterinary Journal*

DOI: 10.1080/00480169.2020.1778580



Scientific Article

Practical oxygen therapy for newborn piglets

AL Soraci^{†}, JM Decundo^{**§}, SN Dieguez^{**#}, G Martinez^{**†}, A Romanelli^{**†}, DS Perez Gaudio^{**†}, MB Fernandez Paggi^{**†‡} and FA Amanto[‡]**

* Department of Physiopathology, Faculty of Veterinary Sciences, National University of Central Buenos Aires Province, Tandil, Buenos Aires Province, Argentina

† Veterinary Research Centre of Tandil (CIVETAN-CONICET-CIC), Tandil, Buenos Aires Province, Argentina

Scientific Investigations Commission of Buenos Aires Province (CIC-PBA), Tandil, Buenos Aires Province Argentina

‡ Department of Animal Production, Faculty of Veterinary Sciences, National University of Central Buenos Aires Province, Tandil, Buenos Aires Province, Argentina

§ Author for correspondence. Email: jdecundo@vet.unicen.edu.ar

Abstract

AIMS: To evaluate the effect of a novel method of practical oxygen therapy on physiological parameters related to survival, weaning weight and preweaning mortality of neonatal piglets under commercial farm conditions.

METHODS: Piglets from hyperprolific sows born with signs of asphyxia, (n=109; <6 on a score of respiration, meconium staining and activity) or very low birth weight (VLBW; n=112; <1.05 kg) were selected for the study. Approximately half of each group (n=55 VLBW piglets and n= 57 piglets with asphyxia) received 100% oxygen immediately after birth using a specially designed facemask for 45 seconds (VLBW) or 1 minute (asphyxiated). Physiological parameters (peripheral blood oxygen saturation (SpO₂) blood glucose concentration and rectal temperature) were measured before oxygen treatment 5 minutes after birth (SpO₂) and 24 hours later (SpO₂, blood glucose concentration, temperature). Weight at birth, at 24 hours and at 21 days of age, preweaning mortality, and estimated colostrum intake were also recorded.

RESULTS: A significant treatment effect on SpO₂ was observed (p=0.013 and p<0.001 for VLBW and asphyxiated piglets respectively). VLBW and asphyxiated piglets that received oxygen treatment had higher SpO₂ after treatment (measured 5 minutes after birth, 97.7 and 97.8% respectively) compared to immediately after birth (93.3 and 86.8% respectively) while untreated piglets showed no variation. Blood glucose concentrations increased in all piglets between birth and

24 hours of age ($p=0.003$ and $p<0.001$ for asphyxiated and VLBW piglets respectively) and this was higher in asphyxiated piglets that received oxygen than those that did not (5.6 (SE 0.2) mmol/L; $p<0.05$). Estimated colostrum intake was higher in asphyxiated (401.6 (SD 24.4) g/kg) and VLBW (374.9 (SE 23.4) g/kg) piglets that received oxygen than those that did not (273.2 (SE 24.1) g/kg; $p<0.001$ and 249.0 (SE 22.5) g/kg; $p<0.001$ respectively). Similarly weight at weaning was higher in asphyxiated (5.8 (SE 0.2) kg) and VLBW (4.9 (SE 0.2) kg) piglets that received oxygen therapy than control animals (4.9 (SE 0.2) kg; $p=0.005$ and 4.1 (SE 0.2) kg; $p=0.008$ respectively). Furthermore, oxygen treatment markedly reduced preweaning mortality from 9/52 (17%) untreated to 1/57 (1.7%) oxygen-treated piglets suffering asphyxia at birth ($p=0.006$).

CONCLUSIONS: Oxygen therapy improves physiological and productive parameters in piglets born with signs of asphyxia or VLBW. The incorporation of this strategy as part of the farrowing routine enhances the advantages of rearing hyperprolific sows.

KEY WORDS: Oxygen therapy, newborn, piglets, birth asphyxia, neonatal mortality

2, 3-DPG	2, 3 diphosphoglycerate
RBC	Red blood cells
RMA	Respiration, meconium staining and activity
SpO ₂	Peripheral blood oxygen saturation
VLBW	Very low birth weight

Introduction

The use of hyperprolific sows in swine production is currently widespread in commercial pig farms around the world (Boulot *et al.* 2008). Through this strategy it became possible to increase the number of weaned piglets per productive sow/year up to 30–36-fold (Tribout *et al.* 2013). However, the benefits of hyperprolificity are often over-shadowed by a significant increase in the number of piglet deaths during farrowing and in the first days of life (Boulot *et al.* 2008). The most relevant causes of neonatal deaths are intrauterine growth retardation (due to metabolic and nutritional deficiencies), sensitivity to cold, hypoglycaemia (correlated with a poor colostrum intake), and crushing of the piglets by the sow (correlated with low vitality at birth) (de Passillé and Rushen 1989, Devillers *et al.* 2011, Theil *et al.* 2014). Furthermore, a meaningful proportion of perinatal

mortalities (10–15%) are associated with severe and/or transitory hypoxia during the farrowing process (Herpin *et al.* 1996). Hypoxia is the failure of the tissues to receive adequate supply of oxygen. Hypoxia in which arterial oxygen pressure is too low to saturate haemoglobin is known as hypoxaemia (or hypoxaemic hypoxia). Perinatal hypoxaemia may result in stillbirth or in asphyxiated newborns (animals born alive but which experience difficulty establishing spontaneous respiration). Predisposing factors for this condition are larger litter size, as these have a higher risk of placental insufficiency causing intrauterine hypoxia (Svendsen *et al.* 1991), low birth weight (<1 kg) (Antonides *et al.* 2015), late birth order (Devillers *et al.* 2007), dystocic births, long intervals between births (Quiniou 2005), inappropriate use of oxytocin during the peripartum period and premature rupture of the umbilical cord (Alonso-Spilsbury *et al.* 2004, Kirkden *et al.* 2013).

Oxygen therapy constitutes a valid strategy to mitigate peripartum hypoxia. As a model for the treatment of hypoxia in human neonates, many studies report the use of oxygen therapy to treat experimentally induced hypoxia in piglets (Tølløfsrud *et al.* 2001, Jantzie *et al.* 2008, Linner *et al.* 2017). However, there are only a few studies of oxygen therapy of piglets focused on swine production. Herpin *et al.* (2001) investigated the effect of oxygen inhalation at birth on the reduction of early postnatal mortality in pigs. They reported that inhalation of 40% oxygen for 20 minutes increased viability and reduced mortality of piglets by 75% during the first day of life. However, the device used and the time required for oxygen inhalation immediately after birth (which delayed first colostrum ingestion), makes implementation of this practice in commercial pig farms difficult. White *et al.* (1996) observed that administration of 100% oxygen to piglets immediately after birth caused a substantial reduction in neonatal mortality. Nevertheless, according to Herpin *et al.* (2001), these results cannot be solely attributed to oxygen therapy, but also to the suite of improvements to farrowing management that had been simultaneously adopted.

The porcine fetus experiences an intrauterine environment of low partial pressure of oxygen as a result of limited oxygen supply through the swine placenta (Comline and Silver 1974). In fetal blood, haemoglobin affinity for oxygen is optimised as consequence of low concentrations of 2, 3 diphosphoglycerate (2, 3-DPG) in red blood cells (RBC) (Delivoria-Papadopulus *et al.* 1974). 2, 3-DPG is an allosteric effector of haemoglobin that reduces its affinity for oxygen and facilitates oxygen release to the tissues. During piglets' neonatal period, rapid physiological changes occur, and the concentration of 2,3 DPG in RBC increases from 1,670 $\mu\text{mol/mL}$ RBC at birth to 2,100 $\mu\text{mol/mL}$ RBC 12 hours later, reaching the adult concentration (10,380 $\mu\text{mol/mL}$ RBC) by around 1 month of age (Delivoria-Papadopulus *et al.* 1974, Głuszek 1979, Watts and Kim, 1984). Higher oxygen saturation may be achieved by oxygen inhalation immediately after birth, when 2,3 DPG levels are still low.

While many modern commercial pig farms have adopted technological advances and innovations, asphyxia at birth is a medical emergency which is frequently poorly managed by farmers and veterinary practitioners. Despite the fact that oxygen therapy has shown to alleviate hypoxic states, it is not included in many maternity management protocols.

The aim of this study was to evaluate the effect of a simple, novel and practical method of oxygen therapy on physiological parameters related to survival, weaning weight and preweaning mortality of neonatal piglets under commercial farm conditions.

Materials and methods

This research was conducted on a commercial pig farm in Buenos Aires Province, Argentina. All procedures for animal handling and experimentation were performed according to the Animal Welfare Committee of the University of the Centre of Buenos Aires Province (FCV-UNCPBA; Tandil, Buenos Aires Province, Argentina) in compliance with EU Directive 2010/63/EU.

Animals and study design

One hundred and fifty, second parity sows of the same genetic line (Maternal line Naïma 2.2; paternal line P76; Choice Genetics, Rafaela, Argentina) were used in this study. During gestation, sows were housed in gestation pens inside an environmentally controlled barn. Three days before parturition sows were moved to a maternity room and housed in individual farrowing pens. Before farrowing, they were fed a commercial gestation feed (Micromix MAX, 3.0 Mcal metabolizable energy (ME)/kg, 14% protein; Biofarma, Rio Cuarto, Argentina) and during lactation, a commercial lactation feed (Micromix MAX, 3.2 Mcal ME/kg, 16% protein; Biofarma). The mean temperature in the farrowing room was 22°C. In the creep area the temperature was 34–35°C for piglets weighing <1 kg and 32–34°C for piglets weighing >1 kg (Manno *et al.* 2005, Caldara *et al.* 2014).

All sows were induced to farrow at 114 days of gestation by I/M injection of 2 mg prostaglandin F2 α (Alfabedyl; Ceva Santé Animale, Libourne, France) per sow. All births were supervised by a swine veterinarian, although, in order to preserve the natural variability of the risk of hypoxia, human obstetric interventions were restricted to routine practices implemented during delivery in this farm. Oxytocin was not used to stimulate uterine contractions in labour.

A mean of 14.5 (SD 2.8) piglets were born alive from each litter. Immediately after birth piglet's oral and nasal cavities were carefully cleared by hand using clean gauze. Each newborn piglet was weighed and evaluated within the first 5 minutes of life. Evaluation included measurement of SpO₂, concentration of blood glucose and rectal temperature (described in detail below). The vitality of each piglet was scored by assigning an RMA score based on the APGAR score (Anonymous 2015;

modified by Rootwelt *et al.* 2012). The RMA score takes into account three variables: respiration, meconium staining and activity each scored from 0–2. These are added to produce the RMA score, which can range from 0–6, where 0 is no respiration or activity and gross meconium staining, and 6 is normal respiration and activity with no meconium staining.

Newborn piglets with very low birth weight (VLBW), defined as <1.050 kg (Antonides *et al.* 2015) and piglets born with asphyxia, defined as an RMA score <6 immediately after birth, were selected for the study. However, piglets with VLBW and RMA<6 were excluded. Piglets were enrolled in the trial until ≥ 100 piglets with each condition were born. Within each group (VLBW or asphyxiated), as piglets were born they were alternately assigned to either receive supplemental 100% oxygen (as below) immediately after evaluation receive no oxygen treatment until ≥ 50 had been assigned to each treatment group. Piglets included in the study were identified by symbols and numbers painted on their backs.

Piglets were then dried using paper towels, umbilical cords were tied and they were placed inside a warm (34–35°C), dry box for a few minutes (maximum 25 minutes) until they stopped shivering and were able to stand. All the interventions, including assistance to establish suckling, followed the regular routine of the farm. Colostrum hand-feeding and cross-fostering were not carried out.

Oxygen administration

Supplemental oxygen (100%, flow rate 10 L/minute) was administered immediately after weighing and RMA scoring (within 5 minutes of birth) for 45 seconds (VLBW piglets) or 1 minute (asphyxiated piglets) (adapted from White *et al.* 1996). For oxygen administration, the piglet's head was placed within a plastic dome mask, specially designed for this study, which was connected to a medical oxygen tank (Air Liquide, Argentina) by a clear flexible PVC tube (internal diameter 1 cm) as shown in Figure 1.

Data collection

All the measurements considered “at birth” were taken within the first 5 minutes of life in the following order:

Peripheral blood oxygen saturation (SpO₂)

Peripheral blood oxygen saturation was measured at birth, 5 minutes later (after oxygen administration) and 24 hours after birth, using a pulse oximeter (Radical-7; Masimo, CA, USA) which was placed on the dewclaw (McCrackin and Swindle 2007). Each measurement was performed twice, with less than 30 seconds between readings, and the mean reported as the SpO₂ value.

Blood glucose concentration

Blood glucose concentration (mmol/L) was measured at birth and 24 hours later, using a portable glucose meter (Accu Chek; Roche Diagnostics GmbH, Mannheim, Germany). Blood samples were taken from the proximal part of umbilical cord as a mixture of venous and arterial blood at birth and from the auricular vein at 24 hours.

Temperature

Rectal temperature was measured in all piglets with a digital thermometer (Ningbo Pinmed Instruments Co., Ltd., Zhejiang, China) at birth and 24 hours later.

Weight

All piglets were individually weighted immediately after birth, 24 hours after birth and at weaning (21 days of age) using digital balances.

Estimation of colostrum intake

Colostrum intake was estimated at 24 hours of age using the method described by Devillers *et al.* (2004) and Devillers *et al.* (2005) using the following equation:

$$CI = -217.4 + 0.217 \times t + 1,861,019 \times BW/t + BW_B \times (54.80 - 1,861,019/t) \times (0.9985 - 3.7 \times 10^{-4} \times t_{FS} + 6.1 \times 10^{-7} \times t_{FS}^2)$$

where CI is the colostrum intake (g), BW_B is body weight at birth (kg), BW is body weight (kg) at age of estimation, t is age of estimation (minutes) and t_{FS} is the interval between birth and first suckling (minutes).

All piglets were monitored by means of a continuous video-recording system (Pro Surveillance System, version 4.04; Zhejiang Dahua Technology Co., Ltd., Hangzhou, China) in order to determine accurately the period of time between birth and first colostrum intake for each piglet.

Prewaning mortality

All piglets were weaned at 21 days of age. Deaths of piglets before this time were recorded as preweaning mortality.

All parameters recorded in this study were measured by trained personnel and supervised by a specialised veterinary professional.

Statistical analysis

For each group (VLBW and asphyxiated piglets), SpO₂, blood glucose concentration and rectal temperature were analysed individually by repeated measures ANOVA where the effects of

treatment, time and their interaction on the dependent variables were considered. The effect of oxygen treatment on colostrum intake was analysed by ANOVA and on weaning weight was analysed by ANCOVA using birth weight as covariate. Normality was evaluated by Shapiro-Wilk test and Bartlett's test was used to assess homoscedasticity. When statistically significant differences were found, comparisons were carried out by Tukey's post-hoc test. Fisher's test was used to analyse associations between oxygen treatment and preweaning mortality percentage for each group. Analyses were performed using R Studio software version 1.1.456 (proc glmer and lm) (RStudio, Inc., Boston, MA, USA).

Results

A total of 221 piglets were enrolled in the study; 112 weighed <1.05 kg (and had an RMA score of 6) at birth and were included in the VLBW group, and 109 had a RMA score of <6 (but weighed \geq 1.05 kg) and were included in the asphyxiated group. Supplemental oxygen treatment was provided to 55 VLBW piglets and 57 asphyxiated piglets while 57 VLBW and 52 asphyxiated piglets did not receive treatment (controls).

The effect of supplemental oxygen administration on SpO₂, blood glucose concentration, colostrum intake and weaning weight of VLBW piglets and asphyxiated piglets are summarised in Table 1 and in Table 2 respectively. Very low birthweight and asphyxiated piglets that received supplemental oxygen showed higher SpO₂ after treatment (measured 5 minutes after birth) which was similar to that measured 24 hours after birth. There was no evidence of an increase in SpO₂ of untreated piglets between birth and 5 minutes later. The SpO₂ of untreated VLBW piglets was no different from that observed for oxygen-treated piglets, after 24 hours of life. However, for asphyxiated piglets, SpO₂ was significantly higher 24 hours after birth but was less than piglets that had received oxygen supplementation.

Blood glucose concentrations were influenced by time and treatment effects. For both VLBW and asphyxiated piglets, blood glucose concentration was higher at 24 hours of life than immediately after birth irrespective of oxygen supplementation. Among asphyxiated piglets, those that received oxygen supplementation showed higher blood glucose concentrations than control animals 24 hours after birth ($p < 0.05$).

There was no effect of oxygen supplementation on rectal temperature for either VLBW or asphyxiated piglets. Rectal temperatures were 36.58 (SE 0.23)°C and 37.64 (SE 0.14)°C at birth and 38.21 (SE 0.11)°C and 38.19 (SE 0.09)°C after 24 hours of life for VLBW ($p=0.243$) and asphyxiated ($p=0.615$) piglets respectively.

Among VLBW and asphyxiated piglets, colostrum intake increased in oxygen-treated piglets compared to control piglets by 50% ($p<0.001$) and 47% ($p<0.001$) respectively. Similarly, oxygen-treated piglets achieved greater weaning weight (at 21 days of life) than untreated piglets with oxygen-treated VLBW and asphyxiated piglets being 0.87 g (21.5%; $p=0.008$) and 0.88 g (17.8%; $p=0.005$) heavier at weaning than those that did not receive oxygen supplementation.

Prewaning mortality (Figure 2) was markedly lower in asphyxiated piglets, which had received oxygen supplementation (1/57; 1.7%) compared to those that had not (9/52; 17%; $p=0.006$). A similar trend was observed for VLBW piglets (3/55 (5.4%) vs. 5/57 (8.7%) for oxygen-treated and control piglets respectively) however the differences were not significant ($p=0.718$).

Discussion

Neonatal pigs have a very low tolerance to hypoxia caused by asphyxia (Randall 1971, Zaleski and Hacker 1993, Herpin *et al.* 1996). Irreversible brain damage has been shown to occur within a few minutes after rupture of the umbilical cord (Curtis 1974, Handman *et al.* 1997, Mato-Rojas *et al.* 2012). Despite this, oxygen therapy is an unusual practice on commercial pig farms. In order to effectively administer oxygen to newborn piglets, we developed a plastic dome hood device adapted to anatomical and morphological characteristics of the head and snout. This low-cost device allowed rapid oxygen delivery, was safe and easy to implement and was very well tolerated by the newborn piglets. As the mask is not sealed, the excess oxygen could exit freely maintaining temperature and relative humidity in the inspired air. In the present work, piglets born with asphyxia or VLBW were strategically oxygenated within the 5 minutes of life, taking advantage of the high oxygen-binding capacity of haemoglobin at birth.

Peripheral blood oxygen saturation of both VLBW and asphyxiated piglets increased after oxygen administration, and there was no evidence that values obtained immediately after the treatment were different to those exhibited after 24 hours of life. In a previous study, Herpin *et al.* (2001) showed significant increases in haemoglobin saturation after 20 minutes of 40% oxygen administration to neonatal piglets. The authors concluded that oxygen inhalation was effective in increasing piglets' arterial oxygen pressure, which is coincident with our results. Even though normal ranges for blood oxygen saturation have not been defined for neonatal pigs, levels above 95% could be considered high based on ranges defined for human infants (Toth *et al.* 2002, Polin *et al.* 2014). In this regard, all piglets in our study reached high SpO₂ levels by 24 hours after birth indicating that despite being born with VLBW or asphyxia, surviving piglets underwent a normal transition process to extrauterine life.

Accurate measurements of blood oxygen in neonatal piglets is a controversial topic and the use of pulse oximetry to measure this has been questioned by several authors (Casellas *et al.* 2004, Orozco-Gregorio *et al.* 2007, Panzardi *et al.* 2013). Yet, pulse oximetry has shown to correlate well with other methods to measure oxygen saturation above 60% in piglets (Faa *et al.* 2014, Solevåg *et al.* 2014). Given that all SpO₂ measurements were >80%, we consider that values for SpO₂ recorded in the present study are likely to accurately reflect piglet's oxygen saturation.

Numerous studies in a variety of species including pigs show that administration of 100% oxygen during neonatal resuscitation can rapidly increase in blood oxygen content together with a consequent risk of oxidative stress (Jenkinson *et al.* 1988, Cheung *et al.* 1998, Mach *et al.* 2011). However, the risk of oxidative stress due to hyperoxia depends on both oxygen concentration and exposure time (Mach *et al.* 2011). Neonatal lung injury from hyperoxia has been observed in newborn piglets which were maintained on 100% oxygen at a flow rate of 8 L/minute constantly for 24 hours (Davis *et al.* 1989). Furthermore, piglets with induced hypoxia which were administered 100% oxygen for 2 hours showed disturbances in brain function associated with alteration of dopamine metabolism (Huang *et al.* 1995; Schears *et al.* 2005). In our study, oxygen administration would be unlikely to cause damage as a result of hyperoxia, due to the short exposure time.

Blood glucose concentration has been considered a marker of neonatal distress and weaning survival since it reflects the homeostatic capability of piglets to compensate for a stressful situation (Baxter *et al.* 2008, 2009). During the suckling period normal blood glucose concentrations remain between 5–6 mmol/L (Duée *et al.* 1996). In the present study, blood glucose concentrations of piglets with VLBW (<1.05 kg) were within normal range by 24 hours after birth. It is important to highlight that there is a great variation in the blood glucose concentrations reported in association with piglets' birth weight and/or previous ingestion of colostrum (Boyd *et al.* 1981, Martinez Rodriguez *et al.* 2011, Mota-Rojas *et al.* 2012). A correlation between birth weight and glycogen pools in the liver has been demonstrated: heavier piglets have larger glycogen pools (Theil *et al.* 2004, Theil *et al.* 2011). Our results showed that, even if piglets are born with VLBW, an adequate capacity to mobilise available metabolic reserves (Close *et al.* 1985, Duee *et al.* 1996), together with proper colostrum and environmental management, may allow them to achieve glucose homeostasis within 24 hours of birth. Blood glucose concentrations in piglets with signs of asphyxia at birth were similar to those obtained by Herpin *et al.* (1996) who reported concentrations of 691–1,000 mg/L in similarly asphyxiated piglets. The metabolic response to the stress of asphyxia at birth is mediated by adrenalin, noradrenaline (concentrations from 12.8–68.0 ng/mL for both neurotransmitters) and corticosteroids that increase concentration of blood glucose by stimulating hepatic glycogenolysis (Herpin *et al.* 1996). Differences in blood glucose concentrations at birth

between individuals may be explained by the stress response to asphyxia during the peripartum period. After 24 hours of life blood glucose concentrations increase as a consequence of colostrum intake (Devillers *et al.* 2011). In our study, asphyxiated animals that received oxygen treatment exhibited significantly higher concentrations of blood glucose which was likely due to the observed increase in colostrum intake.

Normal rectal temperature for neonatal pigs is approximately 38°C (Herpin *et al.* 2002, Baxter 2008, Panzardi *et al.* 2013) but this varies according to environmental temperature and physiological status of the newborn. Thereafter, rectal temperature is highly affected by colostrum intake which enhances thermoregulation. In the present study, oxygen treatment had no effect on rectal temperature of piglets born with VLBW or asphyxia, and temperatures after 24 hours of life were within the normal range. Taking into account that the ideal ambient temperature for piglets (Manno *et al.* 2005, Caldara *et al.* 2014) was maintained in the creep area throughout the trial, it is possible that the poor capacity of VLBW piglets to retain heat and thermoregulate (Herpin and Le Dividich, 1995), might have been improved, in our work by proper control of ambient temperature (Caldara *et al.* 2014). This aspect is not always supervised and often underestimated in commercial pig farming.

For both VLBW and asphyxiated groups, piglets that received oxygen treatment ingested approximately 50% more colostrum than piglets which did not receive oxygen treatment. Le Dividich and Noblet (1981) demonstrated that the lower viability usually reported for piglets with low birth weight or showing signs of asphyxia is likely the result of reduced vigour and suck reflex leading to poor intake of colostrum. Herpin *et al.* (1996) determined that neonatal asphyxia reduces postnatal vitality thus increasing the time required to find the udder and intake the first colostrum. Even though piglets that did not receive oxygen supplementation ingested an adequate amount of colostrum in order to survive, Quesnel *et al.* (2012) reported that oxygen administration immediately after birth improves piglet's vitality and markedly increases colostrum intake. Ingestion of a larger amount of colostrum improves passive immunity, enhances thermoregulatory capacity and promotes gut development (Devillers *et al.* 2007, 2011). All these factors directly impact on the animals' health and productive outcome.

Piglet mortality before weaning was markedly reduced from 17% to 1.7% when piglets born with asphyxia were treated with supplemental oxygen at birth. Pre-weaning mortality in animals with VLBW was also reduced by oxygen treatment. However, this reduction was smaller and not statistically significant. As no power analysis was conducted, the lack of evidence for a difference between treatments may have been due to a lack of statistical power. A greater number of animals

on different farms should be assessed in order to confirm whether oxygen treatment at birth reduces pre-weaning mortality of VLBW piglets, that would represent important productive and economic benefits for commercial pig farming. Accordingly, Devillers *et al.* (2011) observed that colostrum intake is lower in weak piglets, leading to health issues and increasing mortality. Moreover, asphyxia at birth delays, by more than 45 minutes, the first udder contact and intake of colostrum, consequently, decreasing the likelihood of piglets' survival (Herpin *et al.* 1996). In our study, mortality was reduced 10-fold in asphyxiated piglets after O₂ administration, demonstrating that >98% of piglets with signs of asphyxia at birth, might be saved by including this therapy in farrowing management. Our results are in agreement with those of White *et al.* (1996) who obtained a considerable reduction in neonatal mortality (from 18.2% to 10.1%; $p < 0.05$) after employing a farrowing protocol that included oxygen administration to neonatal piglets under similar conditions. In contrast, Casellas *et al.* (2004) and Panzardi *et al.* (2013) found no correlation between oxygen saturation at birth and physiological status of piglets 1 hour later or preweaning mortality. It is possible that rapid increase in SpO₂ after oxygen treatment contributes to enhanced physiological conditions that favour optimum colostrum intake and, consequently, reduced mortality.

We found that weaning weight of piglets at 21 days of age was increased by oxygen administration. VLBW and or asphyxiated piglets that received oxygen at birth, were weaned weighing almost 0.9 kg more than untreated piglets. Devillers *et al.* (2011) established that higher colostrum intake is related to potential long-term effects on piglet growth. Thus the differences in weaning weight are likely to be due to better colostrum intake of oxygen -treated animals leading to optimal physiological and nutritional conditions.

In conclusion, oxygen therapy improves physiological and productive parameters in piglets born with signs of asphyxia or VLBW. Our results show that administration of 100% oxygen, via a suitable device, at birth, represents a practical intervention to take advantage of the production benefits of rearing hyper-prolific lines. Oxygen therapy may easily be incorporated as part of the farrowing routine on commercial pig farms. The economic benefits of this methodology should be evaluated in order to assess its overall impact on commercial pig farming.

Acknowledgements

The authors would like to thank Gabriel Ortiz for collaborating with farm work. This work was supported by CIVETAN-CONICET.

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* Non-peer-reviewed

Submitted 30 July 2019

Accepted for publication 26 May 2020

First published online [insert date]

ACCEPTED MANUSCRIPT

Table 1. Mean (SE) SpO₂ (%), blood glucose concentration (mmol/L), colostrum intake (g/kg) and weaning weight (kg) for very low birth weight (VLBW)^a piglets which received treatment with supplemental oxygen for 45 seconds within 5 minutes of birth (O₂) or did not (control).

Variable	Treatment		P-value		
	Control	O ₂	Treatment	Time	Time by treatment
SpO ₂ (%)			0.013	<0.001	<0.001
Birth	92.9 ± 1.4 ^x	93.3 ± 0.3 ^x			
5 minutes	94.2 ± 0.6 ^{xy}	97.7 ± 0.3 ^{yz}			
24 hours	97.1 ± 0.4 ^{yz}	98.5 ± 0.1 ^z			
Blood glucose (mmol/L)			<0.001	<0.001	0.635
Birth	2.3 ± 0.1	3.1 ± 0.1			
24 hours	5.0 ± 0.1	5.7 ± 0.2			
Estimated colostrum intake (g/kg)	249.0 ± 22.5	374.9 ± 23.4	<0.001		
Weaning weight (kg) ^b	4.0 ± 0.2	4.9 ± 0.2	0.008 ^c		

^{xyz} Values with different superscripts differ (p<0.05)

^a Defined as <1.05 kg at birth

^b Measured at 21 days of age

^c Birth weight was used as covariate p<0.001

Table 2. Mean (SE) SpO₂ (%), blood glucose concentration (mmol/L), colostrum intake (g/kg) and weaning weight (kg) for piglets born with signs of asphyxia^a which received treatment with supplemental oxygen for 1 minute within 5 minutes of birth (O₂) or did not (control).

Variable	Treatment		P-value		
	Control	O ₂	Treatment	Time	Time by treatment
SpO ₂ (%)			<0.001	<0.001	<0.001
Birth	85.1 ± 0.3 ^x	86.8 ± 0.5 ^x			
5 minutes	82.2 ± 0.5 ^x	97.8 ± 0.1 ^y			
24 hours	96.3 ± 0.3 ^z	98.0 ± 0.5 ^y			
Blood glucose (mmol/L)			0.003	<0.001	0.030
Birth	2.9 ± 0.1 ^x	3.0 ± 0.1 ^x			
24 hours	5.0 ± 0.2 ^y	5.6 ± 0.2 ^z			
Estimated colostrum intake (g/kg)	273.2 ± 24.1	401.6 ± 24.4	<0.001		
Weaning weight (kg) ^b	4.9 ± 0.2	5.8 ± 0.2	0.005 ^c		

^{xyz} Values with different superscripts differ (p<0.05)

^a Defined as those with an RMA score <6 where the RMA score is the sum of scores for respiration (0–2), meconium (0–2) and activity (0–2)

^b Measured at 21 days of age

^c Birth weight was used as covariate p=0.016

Figure 1. Photograph of neonatal piglet receiving supplemental oxygen treatment with 5 minutes of birth via a plastic dome mask.

Figure 2. Preweaning mortality (%) in piglets which (a) exhibited signs of asphyxia at birth or (b) had very low birth weight (VLBW) which received supplemental oxygen treatment via a dome mask for 1 minute (asphyxiated piglets, n=57) or 45 seconds (VLBW piglets; n=55) or did not receive oxygen (asphyxiated piglets n=52, VLBW piglets n=57). Bars with different letters are significantly different ($p<0.05$).



