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Effect of method of drying piglets at birth on rectal temperature over the first 24 h after birth[1]

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ABSTRACT: Piglets are born wet, and evaporation of that moisture decreases body temperature, increasing the risk of mortality. The objective of this study was to compare the effect of two commercially applicable methods for drying piglets at birth on piglet rectal temperature over 24 h after birth. The study was carried out in standard commercial farrowing facilities with 52 litters, using a completely randomized design with three Drying Treatments: Control (not dried); Desiccant (dried at birth using a cellulose-based desiccant); Paper Towel (dried at birth using paper towels). Litters were randomly allotted to treatments at the birth of the first piglet. At birth, piglets were individually identified, and the treatment was applied. Rectal temperature was measured at 0, 10, 20, 30, 45, 60, 120, and 1,440 min (24 h) after birth. Data were analyzed using a repeated measures model with PROC MIXED of SAS, with litter as the experimental unit and piglet a subsample of the litter. The model included the fixed effects of treatment and time (as a repeated measure), and the interaction. There was no effect ($P > 0.05$) of treatment on temperature at birth, or 10 or 1,440 min after birth. Piglet temperatures between 20 and 120 min after birth were similar ($P > 0.05$) for the Desiccant and Paper Towel treatments, but were greater ($P \leq 0.05$) than the Control. The effect of birth weight on the response to Drying Treatment was evaluated by dividing the data into Light (<1.0 kg), Medium (1.0 to 1.5 kg), or Heavy (>1.5 kg) piglet Birth Weight Categories. Piglet rectal temperature data at each measurement time were analyzed using a model that included the fixed effects of Birth Weight Category, Drying Treatment, and the interaction. Temperatures of Light piglets were lower ($P \leq 0.05$) than those of Heavy piglets between 20 and 120 min after birth, with Medium piglets being intermediate and generally different to the other two weight categories at these times. The difference in temperature between Light as compared with Medium or Heavy piglets was greater for the Control than the other two Drying Treatments at 60 min after birth. These results suggest that drying piglets at birth is an effective method to reduce rectal temperature decline in the early postnatal period, especially for low birth weight piglets.

Key words: birth weight, desiccant, drying, paper towels, piglet, temperature

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INTRODUCTION

Preweaning mortality is a source of significant economic loss for the U.S. swine sector, a major

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welfare concern, and presents a negative public image of the industry. According to PigChamp (2019) data, preweaning mortality levels have increased on U.S. commercial units over recent years, and currently average approximately 15% of piglets born alive. A major factor associated with this increase is the reduction in average piglet birth weight due to the increase in litter sizes that have occurred in commercial dam lines over a similar time period (PigChamp, 2019). Estimates suggest that approximately 10 to 15% of piglets born are of low birth weight (i.e., weighing <1 kg) and that mortality in these piglets is extremely high, often exceeding 50% (Feldpausch et al., 2019).

A major predisposing factor for preweaning mortality is hypothermia in the early postnatal period (Panzardi et al., 2009). All neonatal piglets are highly cold susceptible; they are born with low body fat for insulation and rely on increasing heat production to maintain body temperature (Herpin et al., 2002). In addition, the piglet is born wet and must expend energy (heat) to dry the body surface. Consequently, in the absence of any intervention, all piglets will experience chilling under typical farrowing room conditions (Curtis, 1974), and are more likely to die from hypothermia (Curtis, 1970). In addition, chilled piglets have reduced vigor and are less able to compete during suckling and, consequently, have reduced colostrum intake (Le Dividich and Noblet, 1981). This reduces the energy intake and immune status of the piglets and predisposes them to dying from other causes, such as starvation, disease, and crushing (Lay et al., 2001; Devillers et al., 2011).

Low birth weight piglets experience the largest postnatal body temperature decline and have the highest levels of preweaning mortality (Tuchscherer et al., 2000). They have greater surface area to body volume ratio than heavier birth weight piglets and, therefore, greater potential to lose relatively more heat in a cool environment (Herpin et al., 2002; Baxter et al., 2008; Theil et al., 2014). They also generally have lower body fat for insulation (Curtis, 1974) and lower energy reserves (glycogen and fat) for heat production (Lossec et al., 1998). Consequently, low birth weight piglets experience a greater postnatal temperature decline than heavier littermates, which can predispose them to higher rates of mortality in the early postnatal period (Panzardi et al., 2013). Our understanding of piglet body temperature changes in the postnatal period, other than in a general sense, is extremely limited, especially under typical commercial conditions. Understanding these changes in body temperature and the effectiveness of potential intervention strategies are critical first steps in developing practically applicable approaches to minimizing temperature decline and to reducing associated mortality.

One potential intervention to reduce the extent of piglet temperature decline is to dry piglets at birth. This approach should reduce heat loss due to evaporation of amniotic fluids from the body surface; however, its effectiveness may vary depending on to the drying material used. While drying has been used commercially, there is limited published information in the scientific literature either on the effect on postnatal body temperature changes, or on the relative effectiveness of the various approaches that can be used. The objectives of this study were to determine typical changes in piglet body temperature in the early postnatal period and the effect of method of drying piglets at birth on these changes. In addition, the effects of piglet birth weight and the potential interactions with drying method on piglet postnatal temperatures were evaluated.

MATERIALS AND METHODS

This study was conducted in farrowing facilities of a commercial breed-to-wean farm of The Maschhoffs, LLC, located near Crawfordsville, IN during the months of December and January. The experimental protocol was approved by the University of Illinois Institutional Animal Care and Use Committee prior to the initiation of the research.

Animals, Experimental Design, Treatments, and Allotment

A total of 52 litters (618 piglets) were used in the study. Sows were from commercial dam lines of Yorkshire and Landrace origin (11 lines in total), that had been mated to commercial sire lines. The study used a completely randomized design, with litter as the experimental unit and piglet as a subsample of the litter, to compare three Drying Treatments: Control—no drying; Desiccant—piglets were dried at birth by coating with a commercial cellulose-based desiccant until completely dry; Paper Towel—piglets were dried at birth with paper towels until completely dry. Litters were randomly allotted to treatment at the start of farrowing after the birth of the first piglet, with the restriction that dam genotype and parity were balanced across treatments across the entire study period. Treatments were applied to entire litters to avoid mixing of dried and undried piglets, as amniotic fluids could be transferred between piglets on different treatments, which could affect subsequent temperature changes.

Housing and Management

Sows were housed in individual farrowing crates, each located within a farrowing pen which had either woven metal or perforated plastic flooring. Crate dimensions were 0.55 m by 1.95 m, giving a floor space within the crate of 1.07 m^2; pen dimensions were 1.52 m by 2.07 m, providing a total pen floor space of 3.15 m^2. Crates were equipped with a sow-operated feed dispenser attached to the feed trough, and a nipple-type water drinker for the sow. An infrared heat lamp was suspended over an insulated rubber mat located in the center of the floor area on one side of the farrowing pen (average temperature under the heat lamp during the study period was 34.3 ± 3.92 °C). Room temperature was maintained using fans and heaters; thermostats were set to 22.5 °C throughout the study period.

Management in the farrowing facility was according to unit protocols, which were generally in line with standard commercial practices. Sows that had not farrowed by d 116 of gestation were induced to farrow on the following day using Lutalyse (2 injections of 1 mL given at 0600 and 1200 h; Zoetis, Parsippany, NJ); the identity of each sow induced and date of induction were recorded. The farrowing process was supervised by the investigators; if the interval between the births of piglets exceeded 60 min, the investigator checked the birth canal for obstructions, and assisted the farrowing process as needed.

Procedures and Measurements

Sows were monitored continuously during farrowing. Piglet rectal temperature was measured at birth, and piglets were given a uniquely numbered ear tag for identification. Piglets on the Desiccant and Paper Towel treatments were dried according to treatment; piglets on the Control treatment were not dried. Immediately after these procedures, piglets on all treatments were returned to the farrowing pen. Piglet and sow rectal temperatures were measured using a HSTC-TT-K-24S-36 thermocouple attached via a SMPW-K-M connector to a dual input K/J digital thermometer (HH801A; Omega, Stamford, CT). Piglet temperatures were measured (at a depth of 2.5 cm) at birth, 10, 20, 30, 45, 60, 120, and 1,440 min after birth; sow temperature was measured at a depth of 10 cm at the start and end of the farrowing process (defined as no piglets expelled for at least 2 h, no piglets in the birth canal, and passage of placenta). Thermometers were calibrated each week during the study period by taking measurements in a temperature-controlled chamber that was set at temperatures that encompassed the expected range (i.e., 30, 32, 34, 36, 38, and 40 °C). Piglets were weighed on the day of birth using a Brecknell LPS-15 bench scale (Avery Weigh-Tronix, Fairmont, MN). Scales were calibrated daily prior to use with a standard test weight.

Farrowing room ambient temperature was measured continuously over the study period using data loggers (Temtop TemLog 20H [Elitech Technology, Silicon Valley, CA]). Ambient temperatures in each farrowing pen (behind and at either side of the sow [one of these measurements being under the heat lamp]) were measured at the beginning and end of the farrowing process using a digital infrared thermometer (TOOGOO GM320 LCD digital infrared thermometer gun [Shenzhen IMC Digital Technology Co., Shenzhen, China]).

Statistical Analysis

The litter of piglets was the experimental unit for all measurements; piglet was a subsample of litter. The PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC) was used to verify normality and homogeneity of variances of the residuals and data were analyzed using the PROC MIXED procedure of SAS (Littell et al., 1996). The study was carried out using a completely randomized design; the model used for the analysis of sow parameters and litter measurements accounted for the fixed effect of Drying Treatment. The model used for analysis for treatment differences in piglet birth weight also included the random effect of piglet within litter. Treatment effects on piglet rectal temperatures at the various measurement times after birth were analyzed using a repeated measures analysis, with the model accounting for the fixed effects of Drying Treatment, measurement time, and the interaction, and the random effect of piglet within litter. A repeated measures statement was included in the model with measurement time as the REPEATED term and piglet as the SUBJECT term in the SAS statement.

An analysis was carried out to determine if the response to Drying Treatments differed according to piglet birth weight. Data were divided into Light (<1.0 kg), Medium (1.0 to 1.5 kg), or Heavy

(>1.5 kg) Birth Weight Categories. The maximum weight for the Light category (i.e., 1.0 kg) represented the birth weight below which preweaning mortality increases substantially (Zotti et al., 2017). The minimum weight for the Heavy category (i.e., 1.5 kg) represented the weight above which preweaning mortality is relatively unaffected by birth weight (Zotti et al., 2017). Piglet rectal temperature data at each measurement time were analyzed using a statistical model that included the fixed effects of Birth Weight Category, Drying Treatment, and the interaction, and the random effect of piglet within litter.

In addition, regression analyses were carried out to determine the effects of piglet birth weight and Drying Treatments on rectal temperature at each time using PROC MIXED. Piglet rectal temperature within time was the dependent variable, and the model included the linear and quadratic effects of birth weight and all interactions with Drying Treatment, and the random effect of sow. Birth weight values were centered before squaring to reduce effects of multicollinearity. A broken-line analysis (with a single slope and plateau) was conducted using PROC NLMIXED for the times that showed a significant quadratic effect of birth weight, with the model including the random effect of sow.

For all analyses, differences between least-squares means were separated using the PDIFF option of SAS, and differences were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

A number of sow parameters and ambient temperatures in the farrowing pen are summarized by treatment in Table 1. There were no differences ($P > 0.05$) between Drying Treatments for any of these parameters or measurements. Sow temperatures before and after farrowing were between 37 and 40 °C, which is typical for farrowing sows (Littledike et al., 1979). Temperatures within the farrowing pens (average between 21.1 and 22.1 °C) were close to the thermostat set point for the farrowing rooms (22.5 °C). Litter sizes and piglet birth weights are summarized by treatment in Table 2. In general, the sows and litters used in the study were typical of commercial production in the United States. The average number of piglets born alive per litter (11.5 to 12.4) was similar to that for U.S. herds reported by PigChamp at the time this study was carried out (13.2 piglets per sow; 2017, 2018). Average piglet weights (1.41 to 1.44 kg) were similar to those reported in recent commercial studies (e.g., Vasdal et al., 2011; Feldpausch et al., 2019).

Table 1. Least-squares means for sow parity, sow rectal temperature, and farrowing pen temperatures during the study, by Drying Treatment

	Drying Treatment[1]				
Item	Control	Desiccant	Paper Towel	SEM	*P*-value
Average sow parity	2.9	4.2	3.6	0.54	0.28
Number of sows by parity[2]					
Parity 2	2	2	3	—	—
Parity 3 and 4	9	7	8	—	—
Parity 5 to 8	6	7	6	—	—
Parity 9+	0	1	1	—	—
Sow rectal temperature, °C					
Start of farrowing	38.5	38.5	38.6	0.15	0.94
After farrowing	38.6	38.7	38.8	0.19	0.72
24 h after farrowing	39.1	39.2	39.3	0.22	0.85
Farrowing pen temperature, °C					
Before farrowing					
Under heat lamp	33.5	35.4	34.5	0.87	0.32
Side of pen opposite heat lamp	21.2	21.4	21.8	0.47	0.61
Behind sow	21.8	21.9	22.1	0.53	0.93
After farrowing					
Under heat lamp	34.9	33.8	33.8	0.89	0.61
Side of pen opposite heat lamp	21.3	21.9	22.1	0.52	0.52
Behind sow	21.3	21.9	21.2	0.50	0.53

[1] Drying Treatment: Control—piglets were not dried; Desiccant—piglets were dried at birth by repeatedly coating and wiping with a desiccant until completely dry; Paper Towel—piglets were dried at birth by wiping with paper towels until completely dry.

[2] Parity—the total number of litters produced by the sow, including the one used in the study.

Table 2. Least-squares means for the effect of Drying Treatment on litter size, birth weight, and rectal temperature of piglets over the first 24 h after birth

	Drying Treatment[1]				
Item	Control	Desiccant	Paper Towel	SEM	*P*-value
Number of litters	17	17	18	—	—
Number of piglets born alive					
Total	210	196	212	—	—
Average per litter	12.4	11.5	11.8	0.86	0.79
Piglet birth weight (born alive), kg	1.44	1.41	1.42	0.026	0.64
Piglet rectal temperature, °C					
Time after birth, min					
0	39.1	39.0	38.9	0.04	0.15
10	37.0	36.9	36.8	0.04	0.27
20	35.9^b	36.7^a	36.4^a	0.04	<0.0001
30	35.6^b	36.9^a	36.5^a	0.04	<0.0001
45	36.0^b	37.3^a	37.0^a	0.04	<0.0001
60	36.3^b	37.7^a	37.4^a	0.04	<0.0001
120	37.6^b	38.3^a	38.1^a	0.05	<0.0001
1,440	38.8	38.8	38.6	0.05	0.10

[a,b] Within a row, means with differing superscripts differ at $P \leq 0.05$.

[1] Drying Treatment: Control—piglets were not dried; Desiccant—piglets were dried at birth by repeatedly coating and wiping with a desiccant until completely dry; Paper Towel—piglets were dried at birth by wiping with paper towels until completely dry.

Temperature Decline of Untreated Piglets

Piglet rectal temperatures for the three Drying Treatments from birth to 1,440 min after birth are presented in Table 2. As expected, temperatures at birth, which were approximately 39 °C, were similar ($P > 0.05$) across all treatments. There is considerable variation between published studies in values for piglet rectal temperature at birth, ranging from 37.8 °C (Vasdal et al., 2011) to 40.5 °C (Pomeroy, 1953). In addition, Kammersgaard et al. (2011) reported considerable variation in birth temperatures within the same study (37.0 to 41.5 °C). Given that piglet temperature declines rapidly immediately after birth (Pattison et al., 1990), differences between studies may be mainly due to the timing of measurement relative to the time of birth.

The temperature decline of the untreated Control piglets provides an estimate of temperature changes that piglets experienced under standard commercial conditions without any intervention. Control piglets experienced an extensive decline in rectal temperature, reaching a minimum (3.5 °C lower than at birth) at 30 min (Table 2). There is considerable variation between studies in the time after birth of and value for the minimum temperature in untreated piglets. In part, this reflects differences in the timing of the first postnatal temperature measurement. In some studies, this was not until 1 h after birth (McGinnis et al., 1981; Tuchscherer et al., 2000; Vila, 2013) and, consequently, the time of the actual minimum temperature was probably missed. Caldara et al. (2014) found that the minimum body surface temperature was reached at 15 min after birth. However, similar to the current experiment, a number of studies have found that the minimum temperature occurred at 30 min after birth (Pattison et al., 1990; Andersen and Pedersen, 2015; Xiong et al., 2018; Cooper et al., 2019). There was considerable variation in the estimates of minimum temperatures between these studies, ranging from 33.6 °C (Xiong et al., 2018) to 36.6 °C (Pattison et al., 1990). Variation between studies in the extent of temperature decline in untreated piglets after birth may be due in part to differences in methodology. For example, measuring body surface temperature using thermal imaging (Caldara et al., 2014) compared with measurement of rectal temperature (e.g., Cooper et al., 2019). In addition, other parameters varied between studies, such as piglet birth weight (e.g., 1.2 kg, Andersen and Pedersen, 2015 compared with 1.5 kg, Cooper et al., 2019) and room temperature (e.g., 18 to 20 °C, Kammersgaard et al., 2011 compared with 23 °C, Xiong et al., 2018). Despite these differences, the overall conclusion from this and previous research is that all piglets experience a large temperature decline in the early postnatal period.

Subsequent to 30 min after birth, the temperature of the Control piglets increased at all measurement times and by 1,440 min approached that observed at birth (Table 2). In agreement, most studies have shown that piglet temperatures approach those observed at birth by 24 h after birth (e.g., Vila, 2013; Xiong et al., 2018; Cooper et al., 2019). These results suggest that, on average, piglets recover from the dramatic early postnatal decrease in temperature and reach normal levels by the end of the first day of life.

Effects of Drying Method

The effects of drying method on piglet rectal temperature over the first 1,440 min after birth are presented in Table 2, and differences in temperature between the Control and the other two Drying Treatments at each measurement time between 0 and 120 min after birth are illustrated in Fig. 1. These measurement times have been chosen to focus on the period when the greatest changes in rectal temperature occurred (i.e., the first 2 h after birth). There was no effect of Drying Treatment on piglet temperatures at 0, 10, or 1,440 min after birth (Table 2; $P > 0.05$). However, between 20 and 120 min after birth, piglets on the Desiccant and Paper Towel treatments had greater rectal temperatures ($P \le 0.05$) than those on the Control (Table 2). There were no differences ($P > 0.05$) between the Desiccant and Paper Towel treatments at any measurement time.

In agreement with other studies (Berbigier et al., 1978; Vasdal et al., 2011; Cooper et al., 2019), the current experiment found no effect of Drying Treatment on temperatures at birth, which was expected given that these measurements were taken before the treatments were applied. Minimum temperatures were reached earlier for the Desiccant and Paper Towel treatments (20 min; 36.7 and 36.4 °C, respectively) than for the Control (30 min; 35.6 °C; Table 2). Relatively few studies measured temperatures frequently enough to compare the timing of minimum temperatures between dried and undried piglets. Berbigier et al. (1978) and Cooper et al. (2019) measured temperatures relatively frequently in the early postnatal period, however, both studies reported treatment differences rather than mean temperatures at each time.

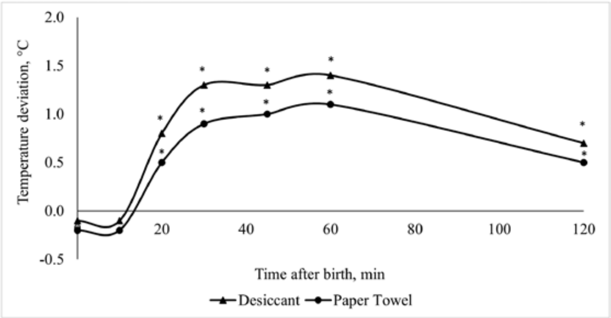

Figure 1. Deviation in piglet rectal temperature between dried (Desiccant or Paper Towel) and undried (Control) treatments over the first 2 h after birth. *Deviation to the Control treatment different from 0, at $P \le 0.05$.

In the current study, the maximum difference between dried and undried Control piglets occurred at 1 h after birth (+1.1 and +1.4 °C for the Paper Towel and Desiccant treatments, respectively; Fig. 1). This timing is similar to a number of other reports (Berbigier et al.; 1978; McGinnis et al., 1981; Cooper et al., 2019), which found the greatest differences in rectal temperature between dried and undried piglets was between 30 and 60 min after birth. However, for these studies, the temperature difference between dried and undried piglets varied, ranging from +0.5 °C for piglets dried with paper towels in the study of McGinnis et al. (1981) to +2.4 °C for piglets dried with a desiccant in the study of Cooper et al. (2019). Cooper et al. (2019) used similar methodology and conditions as the current study, and the difference in the response to the Desiccant treatment in these studies was surprising and warrants further investigation. In general, the results of the current and previous studies suggest that drying (with either a desiccant or paper towels) is effective at reducing both the extent and duration of postnatal temperature decline.

Effect of Birth Weight on Responses to Drying

The least-squares means for the Drying Treatment by Birth Weight Category interaction subclasses for piglet rectal temperature at each measurement time are presented in Table 3. There was no treatment interaction ($P > 0.05$) for temperature at birth, which is in agreement with most studies (Pattison et al., 1990; Caldara et al., 2014; Cooper et al., 2019). There were Drying Treatment by Birth Weight Category interactions ($P \le 0.05$) for temperatures at all measurement times between 10 and 1,440 min after birth (Table 3).

In general, the differences between Birth Weight Categories followed a similar pattern over time within each Drying Treatment. At all measurement times between 10 and 120 min, Light piglets had lower ($P \le 0.05$) temperatures than Heavy piglets, and Medium piglets were generally intermediate and different ($P \le 0.05$) to the other two weight categories (Table 3). The exceptions to this were at 10 min for all three Drying Treatments, and at 60 and 120 min for the Desiccant treatment, when Medium and Heavy piglets had similar ($P > 0.05$) temperatures. Cooper et al. (2019) also showed that

Table 3. Least-squares means for the interaction of Drying Treatment and Birth Weight Category (BWC) on the rectal temperature of piglets over the first 24 h after birth

		Drying Treatment (DT)[1]				*P*-value
		Control	Desiccant	Paper Towel	SEM	DT × BWC interaction
Number of piglets born alive		210	196	212	—	—
BWC[2]						
Light		18	31	25	—	—
Medium		105	92	89	—	—
Heavy		87	73	98	—	—
Piglet rectal temperature, °C						
Time after birth, min						
0	BWC[2]				0.05	0.21
	Light	38.9	38.9	38.7	—	—
	Medium	39.1	39.0	38.8	—	—
	Heavy	39.2	39.0	39.0	—	—
10	BWC[2]				0.05	<0.0001
	Light	35.9^{b}	35.9^{b}	36.0^{b}	—	—
	Medium	36.8^{a}	36.9^{a}	36.6^{a}	—	—
	Heavy	37.5^{a}	37.4^{a}	37.3^{a}	—	—
20	BWC[2]				0.05	<0.0001
	Light	34.0^{d}	35.5^{c}	35.1^{c}	—	—
	Medium	35.7^{c}	36.5^{b}	36.2^{b}	—	—
	Heavy	36.5^{b}	37.3^{a}	37.0^{a}	—	—
30	BWC[2]				0.05	<0.0001
	Light	33.6^{f}	35.5^{e}	34.9^{e}	—	—
	Medium	35.4^{e}	36.9^{bc}	36.3^{d}	—	—
	Heavy	36.3^{cd}	37.6^{a}	37.2^{ab}	—	—
45	BWC[2]				0.05	<0.0001
	Light	33.5^{f}	35.9^{e}	35.2^{e}	—	—
	Medium	35.7^{e}	37.3^{bc}	36.6^{d}	—	—
	Heavy	36.7^{cd}	38.0^{a}	37.8^{ab}	—	—
60	BWC[2]				0.05	<0.0001
	Light	33.4^{d}	36.3^{c}	35.5^{c}	—	—
	Medium	36.1^{c}	37.8^{ab}	37.1^{b}	—	—
	Heavy	37.1^{b}	38.3^{a}	38.2^{a}	—	—
120	BWC[2]				0.05	<0.0001
	Light	35.2^{e}	37.5^{cd}	36.7^{d}	—	—
	Medium	37.6^{c}	38.3^{ab}	38.0^{bc}	—	—
	Heavy	38.2^{ab}	38.7^{a}	38.6^{a}	—	—
1,440	BWC[2]				0.05	0.001
	Light	38.0^{d}	38.5^{abcd}	38.3^{cd}	—	—
	Medium	38.8^{ab}	38.9^{ab}	38.5^{bcd}	—	—
	Heavy	38.9^{a}	38.8^{ab}	38.7^{abc}	—	—

[a,b,c,d,e,f] For each measurement time, means within the DT × BWC interaction with differing superscripts differ at $P \leq 0.05$.

[1] Drying Treatment: Control—piglets were not dried; Desiccant—piglets were dried at birth by repeatedly coating and wiping with a desiccant until completely dry; Paper Towel—piglets were dried at birth by wiping with paper towels until completely dry.

[2] Birth Weight Category: Light—<1.0 kg; Medium—1.0 to 1.5 kg; Heavy—>1.5 kg.

piglets in the lightest birth weight quartile (mean birth weight of 1.13 kg) had temperatures 30 min after birth that were between 0.8 and 1.2 °C lower than those in the three heavier weight quartiles (1.43, 1.62, and 1.81 kg, respectively). Similarly, Pedersen et al. (2016) found that rectal temperature at 2 h after birth in undried piglets increased (35.5, 36.0, and 36.2 °C) with increasing birth weight (1.18, 1.40, and 1.65 kg, respectively). In addition, Pattison et al. (1990) found that piglets with birth weights below 1 kg had lower minimum rectal temperatures (which occurred at 30 min after birth) by 1.6 and 2.3 °C compared with piglets with birth weights of 1.0 to 1.5 kg, or >1.5 kg, respectively.

Birth weight effects were relatively small (≤0.9 °C; Table 3) for all treatments at 1,440 min after birth; however, Light piglets on the Control, but not the other two Drying Treatments, continued to have lower ($P \leq 0.05$) temperatures than heavier littermates (Table 3). Most other studies have also reported that birth weight effects decreased over the first 24 h after birth. Le Dividich and Noblet (1981) found that the percentage of variation in rectal temperature explained by birth weight was high in the early postnatal period (76% at 20 min after birth) but had decreased to less than 5% by 15 h after birth. The results of the current study are in general agreement with this finding, nevertheless, light birth weight piglets continued to have lower temperatures than heavier littermates at 24 h after birth.

Although the general pattern of temperature decline was relatively similar for the three Birth Weight Categories across the three Drying Treatments, the difference between Birth Weight Categories was greater within the Control than within the other treatments. For example, for the Control treatment, the minimum temperature of Light compared with Medium and Heavy piglets occurred later (at 60, 30, and 30 min, respectively) and was lower (33.4, 35.4, and 36.3 °C, respectively; Table 3). In contrast, for the Desiccant and Paper Towel treatments, the minimum temperature occurred at a similar time for the three Birth Weight Categories (30, 20, and 30 min, respectively) and the differences between Birth Weight Categories was relatively small (35.5, 36.5, and 37.3 °C, respectively, for the Desiccant treatment; 34.9, 36.2, and 37.0 °C, respectively, for the Paper Towel treatment; Table 3). These results suggest that heat loss was relatively greater in magnitude and longer in duration for light birth weight piglets, particularly when not dried. This is due in part to the higher body surface to volume ratio in lighter piglets, and the associated greater heat loss relative to body mass.

These results also suggest that the effects of drying of piglets at birth were relatively more effective at reducing temperature decline in light compared with heavier piglets. This is illustrated by the deviations between Control and other two Drying Treatment temperatures for the Birth Weight Categories for the first 2 h after birth which are presented for the Desiccant and Paper Towel treatments in Fig. 2a and b, respectively. There was no difference ($P > 0.05$) in temperature between the Control and either of the Drying Treatments at 10 min after birth (Fig. 2a and b) suggesting that piglets of all weight categories experienced a similar temperature decline within the first 10 min. The main impact of drying is to reduce evaporation of body surface moisture and associated heat loss and this result suggests that evaporation of amniotic fluid may not be the principle cause of heat loss within the first 10 min after birth.

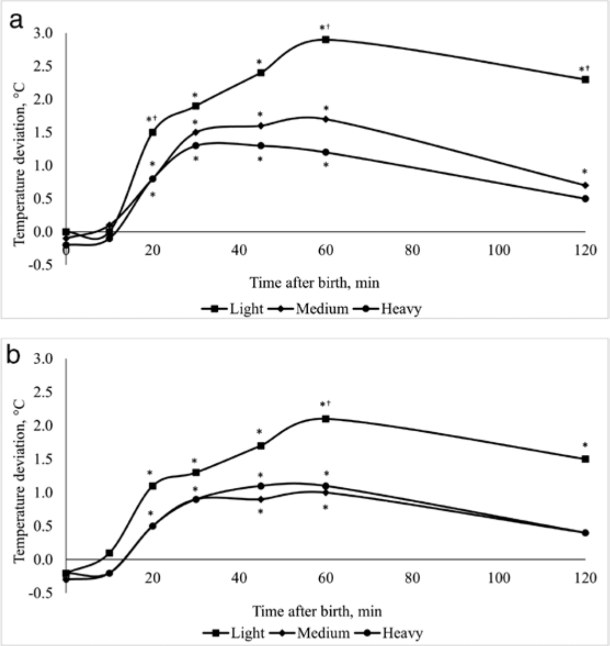

Figure 2. Deviation in piglet rectal temperature between the Control and Desiccant (a) or Paper Towel (b) treatments over the first 2 h after birth, for Light (<1.0 kg), Medium (1.0 to 1.5 kg), and Heavy (>1.5 kg) Birth Weight Categories. †Within each treatment, the deviation from the Control treatment for the Light and Medium Birth Weight Categories differed ($P < 0.05$). There were no differences ($P > 0.05$) between deviations for Medium and Heavy Birth Weight Categories. *Within each treatment, deviation from the Control treatment different to 0 ($P < 0.05$) for each Birth Weight Category.

The deviation in temperature between the Desiccant and Control treatments was greater than 0 ($P \leq 0.05$) for all Birth Weight Categories at all times between 20 and 120 min, with the exception of Heavy piglets at 120 min (Fig. 2a). In addition, the deviation from the Control was greater ($P \leq 0.05$) for Light than Medium and Heavy piglets at 20, 60, and 120 min. For the Paper Towel treatment, the deviations relative to the Control treatment for the three Birth Weight Categories showed similar trends (Fig. 2b); however, the deviation between the Light and the two other weight categories was significant at 60 min after birth only. These results suggest that drying piglets were effective at reducing the extent and duration of piglet temperature decline for all birth weights but was relatively more effective in the lighter piglets and that this approach reduces the variation in postnatal temperature decline due to birth weight. There are no other published studies that have evaluated the interaction between Drying Treatments and piglet birth weight with which to compare the results of the current study.

Table 4. Regression coefficients for the quadratic relationships between piglet birth weight (BW) and rectal temperatures over the first 24 h after birth (as deviations to the Control for the Desiccant and Paper Towel treatments)

Item		Coefficient[2]			SE			*P*-value			
Time after birth, min	Treatment[1]	Intercept	BW	BW^2	Intercept	BW	BW^2	Intercept	BW	BW^2	R^2
0	Control	39.17	0.27	−0.47	0.085	0.080	0.151	<0.0001	0.001	0.002	0.50
	Desiccant	−0.17	−0.11	0.38	0.121	0.120	0.200	0.17	0.34	0.06	
	Paper Towel	−0.28	0.05	0.56	0.120	0.116	0.217	0.02	0.69	0.01	
10	Control	37.02	1.44	−0.49	0.119	0.137	0.258	<0.0001	<0.0001	0.06	0.58
	Desiccant	0.06	0.24	−0.61	0.169	0.205	0.342	0.73	0.24	0.08	
	Paper Towel	−0.09	−0.37	−0.30	0.167	0.199	0.373	0.59	0.06	0.42	
20	Control	35.95	2.13	−1.15	0.137	0.163	0.307	<0.0001	<0.0001	0.0002	0.64
	Desiccant	0.84	−0.24	0.05	0.195	0.243	0.406	<0.0001	0.33	0.91	
	Paper Towel	0.68	−0.74	−0.56	0.192	0.237	0.443	0.001	0.002	0.21	
30	Control	35.76	2.40	−1.54	0.160	0.201	0.377	<0.0001	<0.0001	<0.0001	0.64
	Desiccant	1.35	−0.09	−0.06	0.228	0.300	0.501	<0.0001	0.76	0.9	
	Paper Towel	0.97	−0.73	−0.21	0.225	0.291	0.546	<0.0001	0.01	0.7	
45	Control	36.11	2.69	−1.70	0.182	0.228	0.427	<0.0001	<0.0001	<0.0001	0.64
	Desiccant	1.52	−0.32	−0.56	0.260	0.340	0.568	<0.0001	0.35	0.32	
	Paper Towel	1.13	−0.70	−0.39	0.257	0.330	0.618	<0.0001	0.03	0.53	
60	Control	36.63	3.07	−2.82	0.187	0.247	0.463	<0.0001	<0.0001	<0.0001	0.62
	Desiccant	1.43	−0.75	0.40	0.268	0.368	0.616	<0.0001	0.04	0.52	
	Paper Towel	1.10	−1.05	0.50	0.265	0.360	0.675	0.0001	0.004	0.45	
120	Control	37.95	2.29	−2.69	0.149	0.233	0.427	<0.0001	<0.0001	<0.0001	0.48
	Desiccant	0.60	−0.91	1.12	0.214	0.342	0.570	0.01	0.01	0.05	
	Paper Towel	0.52	−0.84	−0.32	0.212	0.337	0.628	0.02	0.01	0.61	
1,440	Control	38.82	0.63	−0.35	0.124	0.140	0.264	<0.0001	<0.0001	0.19	0.36
	Desiccant	0.00	−0.34	−0.27	0.176	0.211	0.349	0.99	0.11	0.44	
	Paper Towel	−0.22	−0.34	−0.29	0.174	0.203	0.382	0.21	0.04	0.45	

[1] Drying Treatment: Control—piglets were not dried; Desiccant—piglets were dried at birth by repeatedly coating and wiping with a desiccant until completely dry; Paper Towel—piglets were dried at birth by wiping with paper towels until completely dry.

[2] BW, birth weight (kg). Using centered birth weight and squared birth weight, with a mean of 1.42 kg. Desiccant and Paper Towel coefficients as a deviation from the Control.

The quadratic regression coefficients for the relationship between piglet birth weight and rectal temperature at each time point for each treatment are presented in Table 4. For all Drying Treatments, there was a significant quadratic relationship ($P \leq 0.05$) between piglet birth weight and temperature at all measurement times, except at 1,440 min when the relationship was linear (Table 4). In addition, at 0 and 1,440 min after birth, there were relatively limited differences in the regression coefficients between treatments (Table 4). The regression relationships between piglet birth weight and temperature were stronger between 10 and 60 min after birth (R^2 values ≥0.58) than subsequently. Le Dividich and Noblet (1981) also reported that birth weight accounted for a significant but decreasing proportion of the variation in the rectal temperature of undried piglets at times between 20 min ($R^2 = 0.76$) and 15 h ($R^2 < 0.05$) after birth. These regression equations (Table 4) can be used to predict piglet rectal temperature by management strategy and birth weight to identify which piglets are most at risk of hypothermia and may require additional intervention.

Broken-line analyses were carried out for the measurement times that showed a quadratic relationship between birth weight and rectal temperature and these results are presented in Table 5. The break point generally decreased with measurement time for the three Drying Treatments from 10 min after birth, although this change was more variable for the Desiccant than the other treatments. In addition, the break point was generally greater for the Control than for the Desiccant or Paper Towel treatments between 20 and 45 min. The break point represents the threshold weight above which variation in piglet temperature is not influenced by birth weight. These results suggest that the proportion of the population of pigs above this threshold increased over time in all treatments and was greater for dried than undried piglets in the first hour after birth. The plateau temperature (i.e., at and above the break point) for the three Drying Treatments decreased to 30 min after birth and, subsequently, generally increased (Table 5). In addition, between 30 and 120 min after birth, this temperature was generally lower for the Control than for the other two Drying Treatments. The plateau temperature is that at which piglet temperature is not being

Table 5. Broken-line regression for the effect of piglet birth weight on rectal temperature over the first 120 min after birth

		Linear regression below break point			
Time after birth, min	Treatment[1]	Intercept, °C	Slope of birth weight, °C/kg	Break point, kg	Average temperature above the break point, °C
0	Control	36.03	3.73	0.83	39.13
	Desiccant	35.85	4.50	0.70	39.00
	Paper Towel	38.39	0.35	2.07	39.12
10	Control	34.79	1.55	2.12	38.08
	Desiccant	34.17	2.08	1.62	37.54
	Paper Towel	34.84	1.40	2.18	37.89
20	Control	32.70	2.22	2.06	37.28
	Desiccant	33.77	2.09	1.86	37.66
	Paper Towel	32.67	2.84	1.52	36.98
30	Control	31.84	2.67	1.90	36.93
	Desiccant	32.20	3.68	1.46	37.57
	Paper Towel	32.37	3.06	1.60	37.27
45	Control	31.58	3.10	1.83	37.24
	Desiccant	31.91	4.35	1.38	37.90
	Paper Towel	32.02	3.70	1.58	37.86
60	Control	27.22	7.48	1.29	36.87
	Desiccant	27.38	10.19	1.04	38.02
	Paper Towel	32.05	4.06	1.53	38.25
120	Control	27.89	8.71	1.16	37.96
	Desiccant	35.33	2.35	1.43	38.69
	Paper Towel	32.39	4.70	1.32	38.57

[1] Drying Treatment: Control—piglets were not dried; Desiccant—piglets were dried at birth by repeatedly coating and wiping with a desiccant until completely dry; Paper Towel—piglets were dried at birth by wiping with paper towels until completely dry.

influenced by birth weight. These results suggest that, over time, an increasing number of lighter birth weight piglets achieved rectal temperatures equivalent to heavier littermates, and that piglets with lower birth weights that were dried experienced a smaller temperature decline and/or greater temperature recovery across these time periods.

In general, within treatment, the slopes of the regression below the break points increased with measurement time between 10 and 60 min after birth for the Desiccant treatment, and to 120 min for the Control and Paper Towel treatments. The greatest slopes also generally occurred at the same time as the lowest break point weights (with the exception of break points at birth), namely at 60 min for the Desiccant treatment, and 120 min for the Control and Paper Towel treatments. These changes in slopes and break points across measurement times were expected because, as previously described, the temperatures of the Light piglets decreased further and took longer to recover than those of the Medium and Heavy piglets for all treatments. However, compared with the Control and Paper Towel treatments, drying piglets with a desiccant appeared to decrease the time for lighter piglets to recover to a similar temperature as heavier piglets. While there were no significant differences between means for the Desiccant and Paper Towel treatments, these results suggest that the Desiccant treatment may be more effecting at reducing the temperature decline of lower birth weight piglets.

A number of studies estimated the linear regression relationship between piglet body temperature and birth weight at various times after birth, and all showed positive relationships (Pattison et al., 1990; Caldara et al., 2014; Andersen and Pedersen, 2015). However, these studies only evaluated undried piglets, and, therefore, these results can only be compared with the Control treatment of the current study. The magnitude of the regression coefficient reported by other studies varied depending on the measurement time, but were generally greater within the first hour after birth than at subsequent measurement times. For example, Caldara et al. (2014) found that body surface temperature increased by 0.481 and 0.473 °C per kg increase in birth weight at 30 and 45 min after birth, respectively. Andersen and Pedersen (2015) found that rectal temperature increased by between 3.1 and 3.9 °C/kg at times between 15 and 60 min after birth. Pattison et al. (1990) reported an increase of 1.9 °C/kg in rectal temperature at 30 min after birth (the time of the minimum temperature). In the current study, equivalent slopes for the Control below the break point between 20 and 45 min after birth were between 2.22 and 3.10 °C/kg, values that are generally within the range found in previous research. However, the slope at 60 min after birth was 7.48 °C/kg, which is much greater than previously reported. The current study clearly shows that the regression coefficients for relationships between birth weight and rectal temperature vary markedly depending on both measurement time and interventions.

In conclusion, the results of the current study showed that piglet temperatures decline rapidly in the early postnatal period, especially within the first 30 min after birth. Drying of piglets at birth with either a desiccant or paper towels reduced the extent of this decline after 10 min, which suggests that drying was effective. However, there was significant heat loss immediately after birth that was not affected by Drying Treatment and most likely not due to evaporative heat loss. Drying, with either a desiccant or paper towels, reduced the temperature decline for piglets of all birth weights, but had relatively greater effects for low birth weight piglets. Birth weight and Drying Treatment effects on piglet temperature decreased to a minimal level by 24 h after birth, with temperatures for all piglets approaching the levels observed at birth. This suggests that all piglets have the potential to recover from hypothermia and achieve homeothermy. However, the effects of drying on mortality, particularly for low birth weight piglets, warrants further research.

Conflict of interest statement. None declared.

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