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Body Surface Temperature of Suckling Piglets Measured by Infrared Thermography and Its Association with Body Weight Change

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Abstract

The aim of this study was to quantify the body surface temperature of suckling piglets, and determine the association between body surface temperature, body weight and growth rate during the suckling period. The study population consisted of 72 piglets from six sows that were randomly selected at day 4 after farrowing. Infrared thermography and weighing were performed every other day from day 4 to 24 of lactation. Thermal images of each piglet were taken at the eye, base of ear, back, and anus using a handheld infrared camera. Body surface temperature was associated with piglet age and growth rate ($P < 0.05$), but not with body weight. At day 14, the body surface temperature was highest in all regions ($P < 0.05$), while at day 24 the piglets averaged lower body surface temperatures than at days 4-18 ($P < 0.05$). The interaction between piglet age and growth rate significantly affected body surface temperature ($P < 0.05$). The body surface temperature only varied with growth rate in piglets 12 and 14 days old after birth ($P < 0.05$). In conclusion, infrared thermography might be useful for the detection of body surface temperature that can be used as an indication of growth performance in piglets with health problems.

Discipline: Animal industry
Additional key words: Birth weight, early diagnosis, sow, weaning weight

Introduction

Low piglet weight at weaning is associated with a high mortality rate during growth periods and results in a loss of income for the farmer (Tanaka & Koketsu 2008). Thus, it is important for producers to identify piglets with low growth rates early in the suckling period, in order to provide treatment and prevent mortality. Under field conditions, however, it is difficult to measure piglet body weights daily during the suckling period due to the rapid movements of these animals and large size of the farrowing crate, which make it difficult to pick up the piglets. In addition, the frequent restraint and handling of suckling piglets is both labor-intensive and detrimental to their well-being (Chung et al. 2010).

Infrared thermography is a non-invasive technique that permits the recording of body temperature without having touch the animal (Stewart et al. 2008). Body temperature is a fundamental parameter in assessing an animal's health condition (Chung et al. 2010). Thus, a body surface temperature measured by infrared thermography could be useful for the detection of piglets with retarded growth or disease. In pigs, hypothermia is a major cause of neonatal piglet mortality and predisposes piglets to mortality by

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other causes that include starvation, crushing, and disease (Kammersgaard et al. 2011). It has been previously reported that the thermal status of neonatal piglets can be measured by infrared thermography (Kammersgaard et al. 2013). Body surface temperatures have also been measured by infrared thermography in suckling pigs (Chung et al. 2010), growing pigs (Loughmiller et al. 2005), and farrowing sows (Zinn et al. 1985), and this method has also been used to detect fever in growing pigs (Loughmiller et al. 2001). In cattle, infrared thermography is used in developing an early prediction index for infection (Schaefer et al. 2004) or to assess the welfare status of livestock during routine management practices (Schaefer et al. 2012).

Previous studies have reported a correlation between litter weight at birth and litter weight at weaning, with greater birth weights resulting in heavier weaning weights. (Johansen et al. 2004, Gondret et al. 2005, Smith et al. 2007). Some swine producers routinely measure piglet weight at birth and weaning to quantify litter weight. A previous study (Milligan et al. 2001) showed that low birth weight piglets raised with much heavier littermates had slightly lower survival rates, but showed no tendency towards less successful suckling behavior than low birth weight piglets raised with only slightly heavier littermates. At this time, no studies have determined the incremental effects of initial piglet body weight on the daily change and gain in body weight during the suckling period. Moreover, the relationship between body weight and body surface temperature has yet to be investigated.

Therefore, the objective of this study was to quantify the body surface temperatures of suckling piglets at the eye, base of ear, back, and anus, and determine the association between body surface temperature and body weight, weight gain, and piglet age during the suckling period.

Materials and Methods

1. Animals

In conformity with the animal experiment rules of the University of Miyazaki, we were examined as application No. 2012-018, and this application was approved. This study was conducted on a commercial farrow-to-finish farm in Miyazaki prefecture, Japan. The farm averaged approximately 100 sows, and all breeding gilts and sows were Landrace-Large White crossbreds. Piglets from large litters were cross-fostered to smaller litters within the first two days after farrowing to maintain uniform numbers of suckling piglets per sow.

For this study, six multiparous sows with 11-13 suckling piglets each were randomly selected at day 4 after farrowing; thus, the study population consisted of 73 piglets from six sows. All sows were farrowed at the end of July and all piglets were vaccinated against porcine circovirus type 2 on days 12 to 14. Teeth clipping and the castration of male piglets was performed on day 2 after birth.

The experiment was conducted from days 4 to 24 of lactation. All piglets were weaned at day 24 or 25. Each piglet was identified with an ear tag, and all piglets were weighed every other day during the study period by using an electronic scale accurate to 0.1 kg (Tanita HD 660; Tanita Corp., Japan).

2. Capture of infrared thermography images

A handheld infrared camera (Thermo Shot F30, NEC Avio Infrared Technologies Co., Ltd., Tokyo, Japan) was used to collect the thermal images of each pig every other day from day 4. The specifications of the infrared camera that we used are as follows: Infrared detector: uncooled focal plane array (microbolometer); Spectral range: 8 to 14 μm; Measuring range: -20 to 100°C; Sensitivity: 0.1°C at 30°C; Accuracy: ±2°C or ±2% (operating temperature: 0 to 40°C); Detector pixels: 160(H) × 120(V) pixels; Spatial resolution: 3.1 mrad; Focal distance: 10 cm to infinity; Visual camera: CMOS camera 1.3M pixels.

Thermal images were taken at the eye, base of ear, back, and anus (Fig. 1). These four regions were selected based on the results of a preliminary experiment that assessed the association between rectal temperature and skin surface temperature in different areas of the body; the surface temperatures of the four regions selected were all positively correlated with rectal temperature. Every measurement was done at 15:00 to minimize circadian variation, with room temperature also being measured at the same time. To avoid the confounding effect of heat lamps, the piglets were kept outside the heated area for five minutes prior to measurements. The piglets were held during the measurements with the camera was fixed in position, and all images were captured from a distance of approximately 1.0 m from the subject. The thermal images were analyzed using the InfReC Analyzer NS9500 Lite (NEC Avio Infrared Technologies Co., Ltd., Tokyo, Japan) and body surface temperature (°C) was determined in each region.

3. Definitions and categories

The body weight of each piglet was measured every other day from days 4 to 24 by using a digital weight scale. Two-day weight gain was defined as the difference between the body weight of a piglet and its weight two days prior. Table 1 lists the percentile distribution of body weight for each piglet age. The initial body weight was defined as body weight at day 4 after birth. Piglets were categorized into one of three groups based on initial body weight: high (initial body weight within the highest one-third for their litter), middle (initial body weight within the middle one-third for their litter), and low (initial body weight within the lowest one-third for their litter).

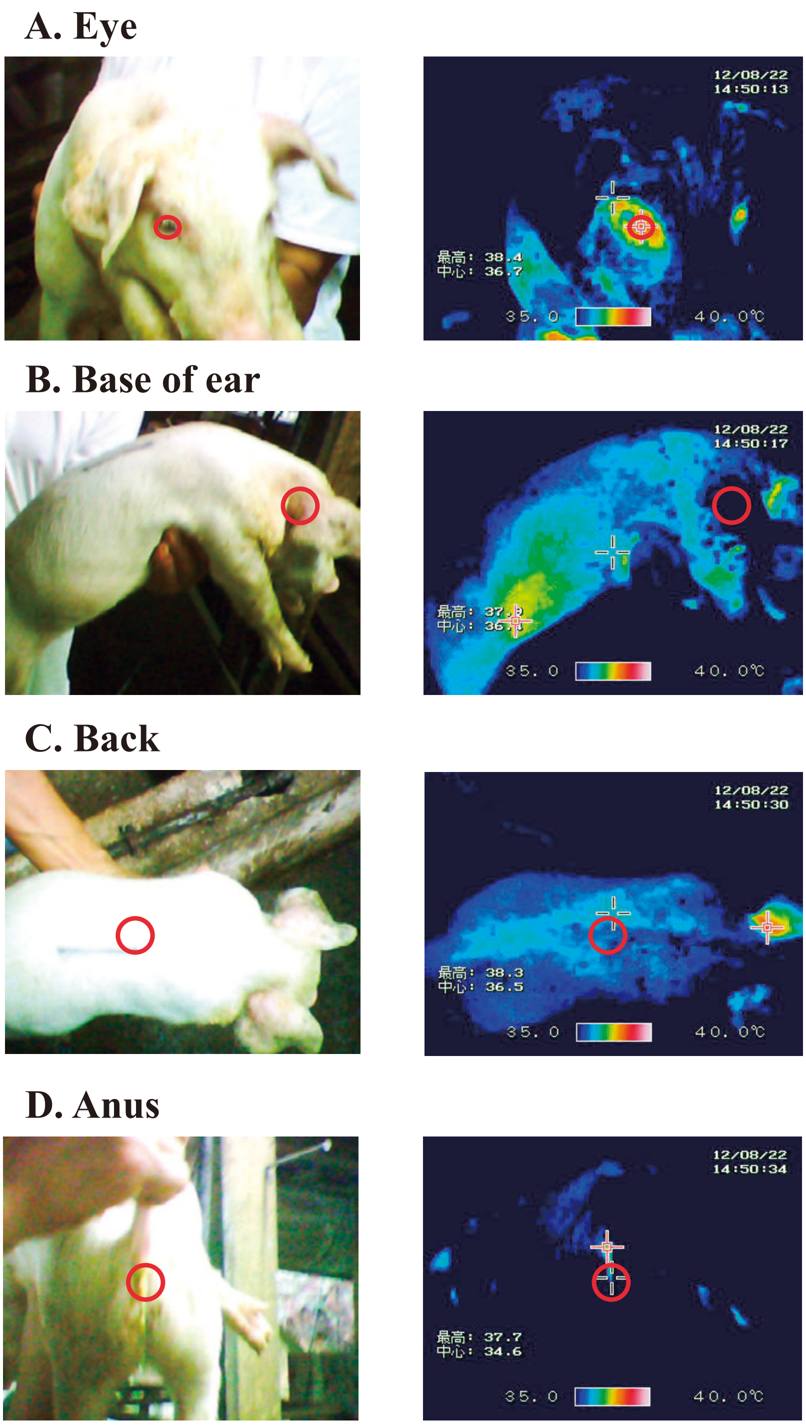

Fig. 1. Sites for body surface temperature measurements (red circles) and corresponding example thermal images. (A) Eye, (B) base of ear, (C) back, and (D) anus

4. Statistical analysis

Statistical analyses were conducted using SAS version 9.3 (SAS Inst. Inc., Cary, NC, USA). Correlations between the body surface temperatures in the four selected regions were assessed using Pearson's correlation analysis. A linear mixed-effects model using the MIXED procedure for repeated measures was used to analyze body weight, two-day weight gain, and body surface temperature in the four selected regions. Model 1 was performed to determine the effect of initial body weight on subsequent body weight. The dependent variables were body weight or two-day weight gain. The independent variables were the three initial body weight groups and piglet age. Model 2 was constructed to identify the factors associated with body surface temperature. The dependent variable was body surface temperature in the four selected regions. The independent variables were piglet age, the three initial body weight groups, and two-day weight gain. Both models included piglets as the subject and sow as a random effect. All possible two-way interactions between the significant main effects were initially included in the models, and then removed if not significant. All significant main effects and interactions were tested using Tukey-Kramer multiple comparison tests. P values of < 0.05 were considered significant.

Results

The average room temperature ± SD at thermal image capture was 29.3 ± 1.41°C (range of 27.0°C to 31.0°C). One piglet died on day 10 of the study period; therefore, measurements obtained from 72 piglets from six litters were used for analysis. Individual body weights for each litter at day 4 and day 24 ranged from 1.7 ± 0.14 kg to 2.4 ± 0.11 kg and from 4.6 ± 0.32 kg to 5.9 ± 0.24 kg, respectively. During the study period, the average body weight of the 72 piglets increased from 2.0 ± 0.05 kg at day 4 after birth to 5.3 ± 0.14 kg at day 24 (Table 1). In addition, the interaction between piglet age and initial body weight significantly affected body weight ($P < 0.05$; Fig. 2). The difference in body weight between the piglets in the three initial body weight categories increased over the study period ($P < 0.05$; Fig. 2). Average two-day weight gain during the study period was 0.32 ± 0.01 kg/2 days. Two-day weight gain was associated with piglet age and initial body weight category ($P < 0.05$; Table 1, Fig. 3). Two-day weight gain from days 8 to 14 was higher than from days 16 to 22 ($P < 0.05$; Table 1). Piglets in the low initial body weight category gained less weight every two days relative to those in the middle and high initial body weight categories (0.27 ± 0.01 vs. 0.33 ± 0.02 and 0.37 ± 0.02 kg/2 days; $P < 0.05$). There was no interaction between piglet age and initial body weight for two-day weight gain (Fig. 3).

Overall, the mean body surface temperatures at the eye, base of ear, back, and anus were 35.5 ± 0.04, 39.5 ± 0.03, 37.9 ± 0.03, and 38.6 ± 0.03°C, respectively. There was a positive correlation (r = 0.52 to 0.82) between the body surface temperatures of the four selected regions (P < 0.05; Table 2). Body surface temperature was associated with piglet age and two-day weight gain ($P < 0.05$; Fig. 4), but not with initial body weight category. Piglets had the highest body surface temperature at day 14, following vaccination ($P < 0.05$). At day 24, piglets had lower body surface temperature than at days 4 to 18 ($P < 0.05$; Fig. 4). In addition, there was significant interaction between piglet age and two-day weight gain for the body surface temperature at all four regions ($P < 0.05$; Fig. 5). Body surface temperature varied with weight gain only on days 12 and 14 ($P < 0.05$; Fig. 5).

Table 1. Comparisons of two-day weight gain of 72 piglets by age

Piglet age	Body weight, kg	Body weight percentile				Two-day weight gain, kg/2 days
		10th	33th	67th	90th	
Day 4	2.0 ± 0.05	1.5	1.9	2.2	2.6	–
Day 6	2.4 ± 0.06	1.7	2.1	2.6	3.1	0.32 ± 0.03abc
Day 8	2.8 ± 0.07	2.0	2.4	3.0	3.5	0.38 ± 0.02a
Day 10	3.2 ± 0.07	2.3	3.0	3.4	4.0	0.41 ± 0.02a
Day 12	3.6 ± 0.09	2.6	3.3	3.9	4.6	0.43 ± 0.03a
Day 14	4.0 ± 0.10	2.9	3.7	4.4	5.1	0.41 ± 0.03a
Day 16	4.2 ± 0.10	3.1	3.9	4.6	5.2	0.21 ± 0.03c
Day 18	4.4 ± 0.10	3.3	4.2	4.9	5.4	0.23 ± 0.03c
Day 20	4.7 ± 0.11	3.4	4.3	5.2	5.8	0.25 ± 0.02bc
Day 22	4.9 ± 0.13	3.3	4.5	5.2	6.2	0.23 ± 0.03c
Day 24	5.3 ± 0.14	3.6	4.9	5.6	6.8	0.37 ± 0.03ab

a - c. Values (Mean ± SEM) within a column with different superscript letters differ significantly ($P < 0.05$).

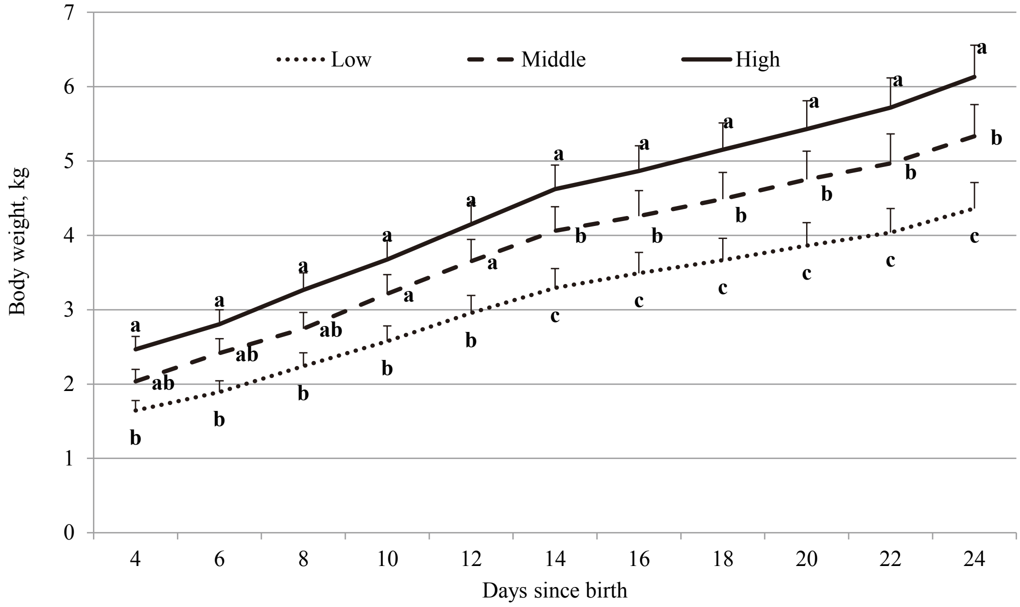

Fig. 2. Change in body weight of each initial (day 4) body weight group over the study period (Mean ± SEM). Different letters indicate significant differences between the initial body weight groups on each day (a > b > c, *P* < 0.05).

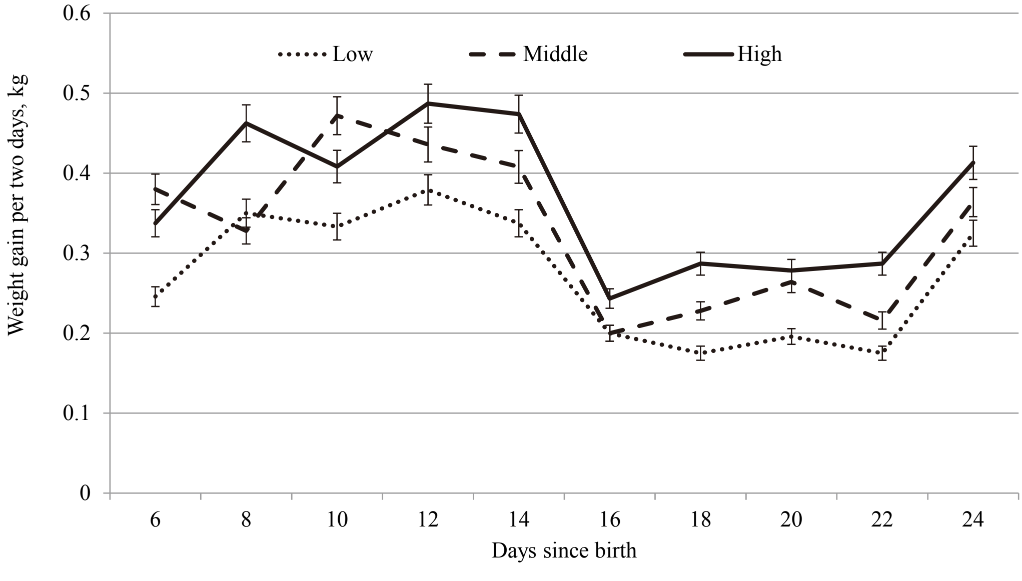

Fig. 3. Change in two-day weight gain of each initial (day 4) body weight group over the study period (Mean ± SEM). Piglets with low initial body weight had lower two-day weight gain than those in the middle and high initial body weight groups, regardless of age (low, 0.27 ± 0.01 kg/2 days; middle, 0.33 ± 0.02 kg/2 days; and high, 0.37 ± 0.02 kg/2 days; *P* < 0.05).

Discussion

In this study, we measured the body surface temperature of suckling piglets every two days by using infrared thermography. Surface temperatures varied at different regions of the body. The average rectal temperature in pigs is approximately 39°C (range 38-40°C; Jackson & Cockcroft 2005). Body surface temperature at the base of the ear, back, and anus were within this range, but eye temperature was lower than at the other regions. In contrast, the temperature of the eye surface in cattle is higher than at other regions, and considered a non-invasive indicator of the animal's core temperature (Gloster et al. 2011). The biological reason for this difference is unknown, but there may be a variation within species.

The piglets in this study were held while thermography images were obtained to accurately measure their body surface temperature. However, the positive correlation between the body surface temperatures of the four regions selected for measurement in this study suggests that any of those selected regions could be used to detect the temperature of suckling piglets. Therefore, the animals applicable to such detection on a farm need not be handled at such time. Repeated rectal temperature measurements and restraint could lead to nervousness in pigs, and possible restraint could induce rectal injuries (Chung et al. 2010). Thus, infrared thermography would be preferable to rectal temperature measurements in monitoring piglet health.

Table 2. Correlations between regional body surface temperatures of 72 piglets

	Correlation coefficient (r)			
	Eye	Base of ear	Back	Anus
Eye	-	0.60*	0.54*	0.52*
Base of ear		-	0.82*	0.72*
Back			-	0.68*
Anus				-

* indicates $P < 0.01$.

In this study, the average two-day weight gain (0.32 ± 0.01 kg/2 days), was relatively similar to a previously reported average of 0.21 kg/day (Johansen et al. 2004); however, body surface temperature and weight gain were correlated only on days 12 and 14. On these days, piglets with lower body surface temperatures gained less weight than those with higher temperatures. This could be associated with vaccination (performed between days 12 and 14) because external stress decreases feed intake and daily weight gain (Lindemann et al. 1987). These findings indicate that body surface temperature might be related to the growth performance of piglets with growth problems. Extra attention should be given to piglets that lose or maintain their body weight after vaccination, but fail to gain weight, because these animals are presumed to be at greatest risk of being crushed due to low activity levels (Weary et al. 1996).

In contrast to the relationship between body surface temperature and weight change, we found no relationship between body surface temperature and body weight. This indicates the difficult in using infrared thermography to detect litter variations in piglet weight.

Our findings suggest that the early body weight of

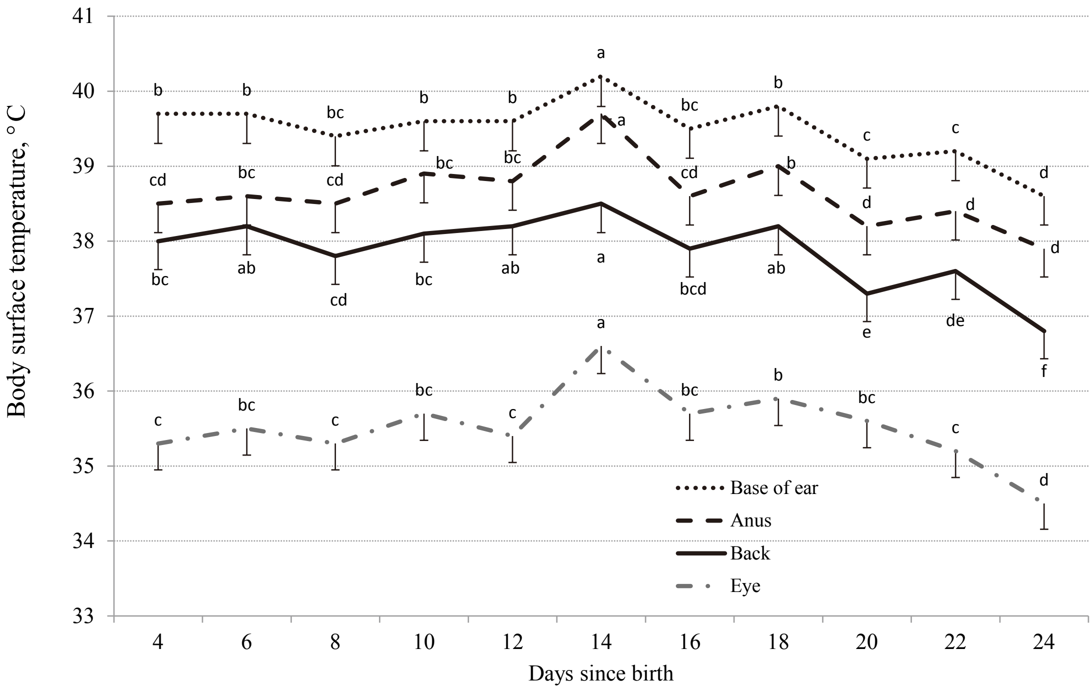

Fig. 4. Comparisons of body surface temperatures at each of four anatomic sites in 72 piglets over the study period (Mean ± SEM). Different letters indicate significant differences between the days at each anatomic site (a > b > c > d, *P* < 0.05).

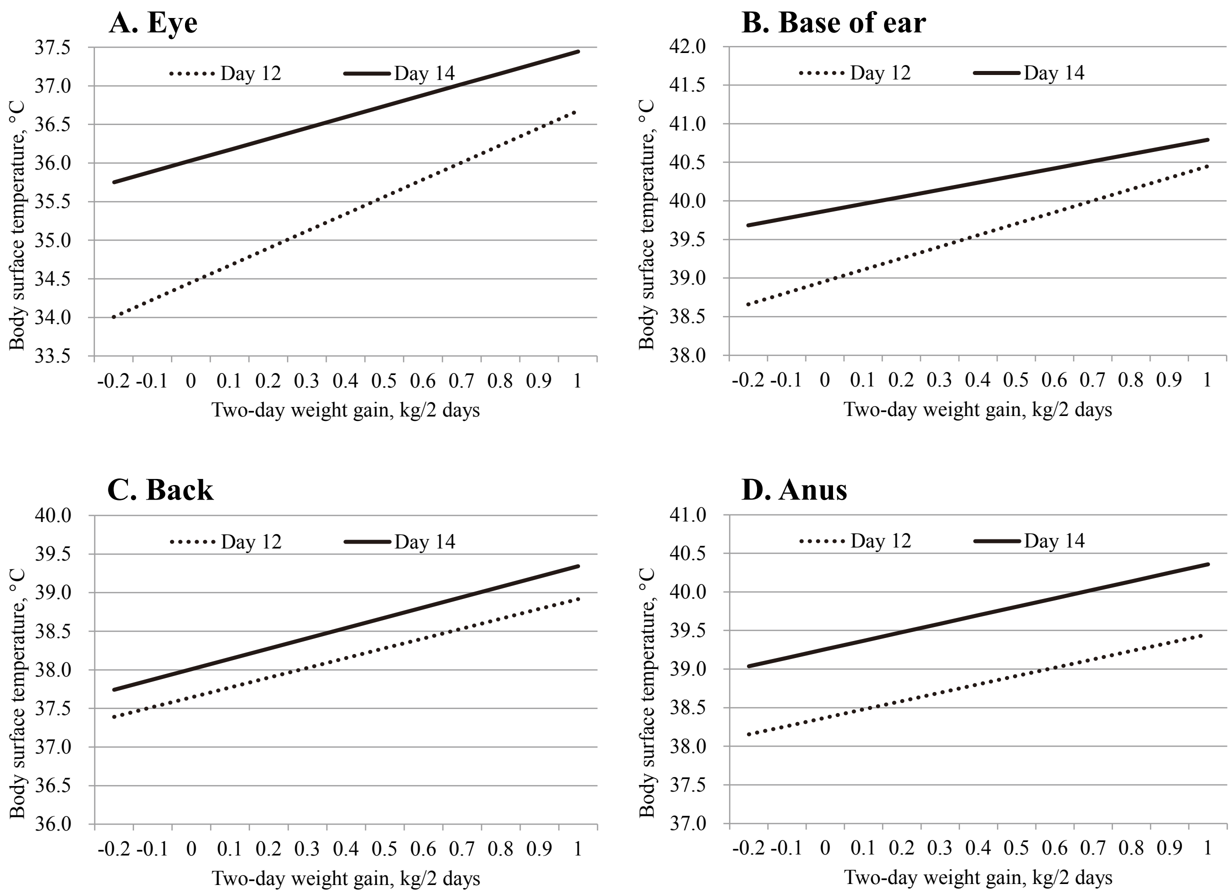

Fig. 5. Predictive equations for change in body surface temperature with two-day weight gain at four anatomic sites. A) Eye, at day 12 {y = 34.4512 (±0.2485) + 2.2235 (±0.4838) x} and at day 14 {y = 36.0277 (±0.2323) + 1.4119 (±0.4695) x}; B) base of ear, at day 12 {y = 38.9586 (±0.1730) + 1.4902 (±0.3185) x} and at day 14 {y = 39.8673 (±0.1653) + 0.9233 (±0.3208) x}; C) back, at day 12 {y = 37.6449 (±0.1699) + 1.2713 (±0.3305) x} and at day 14{y = 38.0092 (±0.1616) + 1.3327 (±0.3333) x}; and D) anus, at day 12 {y = 38.3703 (±0.2122) + 1.0805 (±0.4061) x} and at day 14{y = 39.2569 (±0.2021) + 1.1015 (±0.4108) x}.

piglets affects the growth rate during lactation and the body weight at weaning. This is consistent with the association between birth weight and weight at weaning as previously reported (Miligan et al. 2001, Gondret et al. 2005, Smith et al. 2007, Beaulieu et al. 2010). However, the results of the present study clarified that piglets with low weights at weaning had poor growth throughout the entire suckling period. Piglets having low birth weights are less likely to suckle from one of the anterior teats, with suckling order and position remaining constant throughout lactation (Milligan et al. 2001). Consequently, split-suckling, intermittent suckling, or split weaning are effective techniques for increasing piglet weight (Kuller et al. 2004, Skok & Škorjanc 2013).

One limitation of this study is that the initial body weight of the piglets was measured at day 4 after birth instead of at birth. We chose to begin our observations at day 4 to minimize the effect of piglet death, which mostly occurs within three days after birth (Koketsu et al. 2006), on our data set. However, our initial body weights are not actual birth weights. In addition, outcomes might possibly differ in different operations or genetic lines. Further investigation is needed to clarify how to use infrared thermography under field conditions.

The present study was conducted under field conditions. Therefore, specific environmental conditions such as air temperature may affect body surface temperature. A previous study found a positive correlation between air temperature and body surface temperature (Loughmiller et al. 2001). However, the effect of air temperature would be minimized in this study because room temperature was kept within a narrow range between 27.0°C and 31.0°C. The effect of wide-ranging environmental conditions must also be taken into account. Furthermore, in this study, every measurement was done at 3 p.m. to minimize circadian variation. In addition, the piglets were kept outside the warm room for five minutes prior to measurements, with the camera being fixed at a distance of approximately 1.0 m from the measurement regions.

In conclusion, infrared thermography might be useful for detecting piglets with growth problems, but cannot be used to detect weight variations among piglets in a litter. The use of infrared thermography could allow the rapid detection of piglets with growth problems and thus facilitate prompt treatment. In addition, our findings suggest that weighing piglets early in the suckling period may identify those piglets less likely to grow well, and thus allow targeted intervention to improve production and the chances for post-weaning survival.

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