Thermal imaging as a potential tool for identifying piglets at risk

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Introduction

Newborn piglets are more susceptible to cold than to heat stress, and cold stress is one of the most significant stressors encountered early in life (Herpin *et al.*, 2002). Piglets usually experience a sudden drop in ambient temperature at birth (range: 15-20 °C), which normally results in a 2 to 4 °C drop in core body temperature (Lossec *et al.*, 1998). The ability to conserve heat is very limited due to the piglets' lack of brown adipose fat, relatively large body surface-to-volume ratio, and sparse hair coat (Herpin *et al.*, 2002).

Pig numbers per farm in Australia (APL, 2009-2010) and Europe (Blokhuis *et al.*, 2003) have increased while the ratio of stockmen to animals has severely declined, making the recognition of piglets at risk extremely important. Detection of these animals (visual, clinical or serological examinations) in large operations is challenging and stockmen are often unable to identify all at risk animals at an early stage (Blokhuis *et al.*, 2003). Consequently, opportunities to intervene are limited, resulting in higher mortality rates.

Core body temperature is usually measured rectally using a glass-mercury or a digital rectal thermometer. These tools are still invasive, practically challenging for implementation in large populations, and requires extra labour resources. Infrared thermography (IR), on the other hand, is a modern and non-invasive technique for monitoring temperatures and can accurately monitor small changes in temperature. Infrared thermography has been used to detect foot and mouth disease in beef cattle (Rainwater-Lovett *et al.*, 2009), stress in pigs (Schaefer *et al.*, 1989), and bull infertility (Lunstra and Coulter, 1997).

The aim of this experiment was to investigate the use of thermal imaging as an early diagnostic tool to identify hypothermic piglets.

Materials and Methods

The study was conducted on piglets (n=630) born in 62 purebred litters of primi- and multiparous sows from two maternal (Large White and Landrace) and two terminal (Duroc and Large White) lines. Piglets were born in a single herd in late summer between February and March 2010.

Data collection

Infrared thermography images were taken for each litter within 24 hours of farrowing *in situ* to establish which measurement sites would normally be visible during a routine inspection without handling piglets. Each piglet in a litter was given a temporary number (1-n) and allowed to settle before the IR images were taken. Multiple images were taken per litter if necessary to observe all piglets at least once. The most informative image for an individual piglet was used.

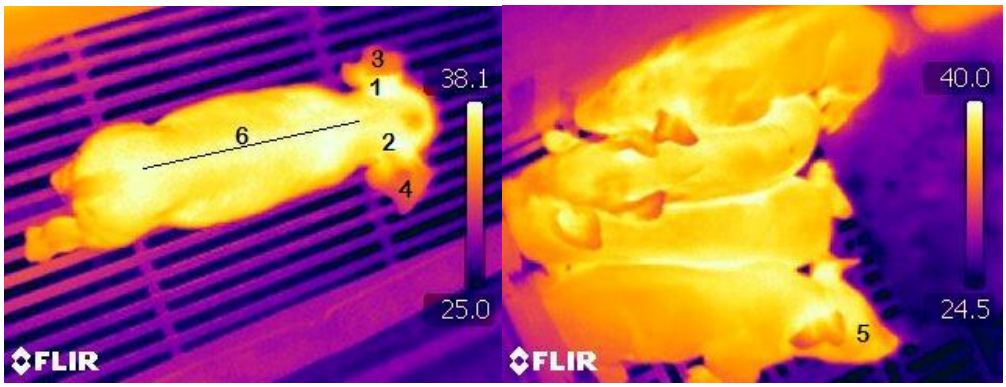

Figure 1. Anatomical regions measured: 1= base of the left (BEAR_L); 2= base of the right ear (BEAR_R); 3=tip of the left ear (TEAR_L); 4=tip of the right ear (TEAR_R); 5=left or right eye (EYE_O); 6=average temperature of the crown to rump length AVCRL.

The digital images were converted into comma-separated value (csv) files through the ThermaCam Researcher Professional 2.9 (FLIR Systems). These images were used to generate a range of data points corresponding to defined locations on the piglet using an in-house program (ThermAnal 2.6, C#.net program, AGBU, UNE).

Apart from the six specific areas examined (Figure 1), the average values for the base (AVBEAR) and tips (AVTEAR) of the ears were also calculated. They were referred to as IR traits. Rectal temperature (RTEMP), birth weight (BWT), the absence and presence of shivering (SHIV), and individual piglet survival until weaning (SURV) were also recorded.

Data analysis

General linear models were used to investigate whether IR and the other piglet traits were influenced by systematic effects. The effects examined were farrowing week (5 levels), line (2 levels), sow parity (4 levels), and piglet gender (2 levels). The total number of piglets born in the litter (TB) was treated as a linear covariate. Differences between trait means were compared using a paired t-test. The Welch two sample t-test was used to compare the mean temperature differences between the non-shivering and shivering piglets.

Pearson's correlation was used to determine the strength of relationships between all traits. Only animals with all measurements at all anatomical regions (n=485) were included; the trait EYE_O was excluded from this analysis due to its low number (n=17) of records. Linear regression was also performed to illustrate the associations between RTEMP and IR temperatures.

Results and discussion

Characteristics of the data

Differences in the number of records occur for body temperature traits due to the piglet's orientation and/or position in the pen when the IR pictures were taken (Table 1). Based on the *in situ* images, it was easiest to obtain records on AVCRL, followed by tips of ears, the base of ears, and eyes. About 10% of piglets did not generate at least one IR record for the ears.

Table 1. Characteristics of the data (n=630 piglets).

Variables	N	Mean (SD)	Range	CV%
BEAR_L (°C)	539	38.1 (1.39)	30.8 – 41.8	4
BEAR_R (°C)	545	37.9 (1.40)	30.8 – 41.6	4
AVBEAR (°C)	494	37.9 (1.34)	30.8 – 41.5	4
TEAR_L (°C)	575	34.2 (2.81)	26.6 – 41.5	8
TEAR_R (°C)	587	34.4 (2.71)	27.3 – 42.9	8
AVTEAR (°C)	558	34.3 (2.67)	27.4 – 40.5	8
EYE_O (°C)	17	37.6 (1.67)	33.3 – 40.4	4
AVCRL (°C)	628	37.7 (1.31)	30.8 – 41.8	3
RTEMP (°C)	625	38.2 (0.70)	32.5 – 39.6	2
BWT (kg)	630	1.59 (0.35)	0.57-2.63	22
SHIV (0/1)	625	1.09 (0.29)	1 – 2	27
SURV (0/1)	630	1.85 (0.36)	1 – 2	19

Only a small number (n=17) of piglets were captured with a clear view of either the left or the right eye. While the number of records was low for EYE_O, its mean IR value was 37.6 °C, which was similar to AVCRL, but slightly lower than RTEMP (38.2 °C). From the paired *t*-test (n=16), the mean RTEMP and IR value for EYE_O were not significantly different at P<0.05, but *n* is too low to be conclusive. Infrared temperature of the eye has been suggested as a practical proxy for core body temperature to identify animals with fever for further examination (Gloster *et al.*, 2011). However, this study clearly illustrated that the IR temperatures of the eyes were very difficult to obtain without a controlled pickup, which is unfeasible in practical applications. Due to the low number of records obtained, no further analysis was done for EYE_O.

The mean value for RTEMP (38.2 °C) was significantly higher (P<0.01) than the mean value for AVCRL (37.7 °C). Mean temperatures for BEAR_L and BEAR_R were 38.1 and 37.9 °C, respectively and the paired t-test showed no significant difference (P=0.72) between temperatures recorded at the same site on different sides of the body. Ear or tympanic membrane temperature had also being used to measure the core temperature of human infants (Hughes *et al.*, 1985) and viral infected calves (Schaefer *et al.*, 2004). It can be measured through the ear canal or behind the ear lobe (Hughes *et al.*, 1985). Paired t-test from this study showed significantly lower IR values for BEAR_L (P<0.01) or BEAR_R (P<0.001) compared to RTEMP (38.1 or 37.9 °C vs 38.2 °C), and between AVBEAR (P<0.01) and RTEMP (37.9 vs 38.2 °C). Temperatures measured at the ear base were 0.3 °C lower than the rectal temperature recorded for the same piglets.

Mean temperatures recorded at the tips of ears were relatively low (range: 34.2 to 34.4 °C). According to Radostits *et al.* (2000), cold piglets may exhibit shivering and trembling, with the skin of extremities (nose, tail, and ears) feeling cool to the touch. However, our results suggest that manual palpation of these extremities is a subjective and unreliable way of assessing the piglet's thermal state, which merely measures the presence of a temperature gradient between the animal's body surface and the human hand (Palmer, 1981). Shivering thermogenesis, on the other hand, is only possible when the core body temperature is above 34 °C (Herpin *et al.*, 2002; Lossec *et al.*, 1998). This suggests that piglets in deep hypothermic phase would not be identified if shivering or cold extremities are used as the only clues for low body temperature. In spite of the warm summer ambient temperatures during the study period and provision of heat lamps, 9% of piglets were shivering. A much higher percentage of piglets were observed shivering in cooler months (Tabuaciri, 2012).

Overall, standard deviations of body surface IR temperatures were higher than corresponding standard errors for rectal temperatures. All IR traits were more variable (CV~8%) relative to the mean when compared to RTEMP (CV=2%). For animals with both BEAR and TEAR records, measurements at the ear tips were both lower and more variable than measurements taken at

the base of the ears, consistent with the explanation of colder and more variable temperatures of extremities.

Correlations between infrared thermography (IR) traits

The absence of consistently significant systematic effects that are explanatory variables for IR traits suggested that the Pearson's correlation was adequate to observe associations between IR traits, and trait values did not need adjustment to enable comparisons.

Table 2. Pearson correlation coefficients between measured points (N=485).

	BEAR_L	BEAR_R	AVBEAR	TEAR_L	TEAR_R	AVTEAR	AVCRL	RTEMP	BWT
BEAR_L (°C)	1.00								
BEAR_R (°C)	0.95	1.00							
AVBEAR (°C)	0.99	0.99	1.00						
TEAR_L (°C)	0.80	0.70	0.76	1.00					
TEAR_R (°C)	0.52	0.32	0.43	0.81	1.00				
AVTEAR (°C)	0.73	0.60	0.68	0.98	0.92	1.00			
AVCRL (°C)	0.90	0.83	0.87	0.67	0.43	0.61	1.00		
RTEMP (°C)	0.80	0.88	0.85	0.39	-0.004	0.27	0.75	1.00	
BWT (kg)	0.35	0.29	0.32	-0.06	-0.29	-0.14	0.41	0.47	1.00

Overall, correlations between left and right IR measurements (where relevant) within anatomical regions (BEAR_L vs BEAR_R, TEAR_L vs TEAR_R) were higher than correlations between regions, with a higher correlation between each region and the average, due to autocorrelation. Yaron *et al.* (1995) measured the accuracy of the infrared tympanic thermometer on human patients and found a strong correlation between the tympanic temperature of the two ears, indicating that taking the IR temperature reading of either ear is sufficient. This study showed a similar outcome when temperature was recorded at the base of the ears.

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In contrast, correlations were lower between the base (BEAR_L and BEAR_R) and the tips (TEAR_L and TEAR_R) of the ears, ranging between 0.33 to 0.80, with a value of 0.68 between AVTEAR and AVBEAR. This was expected as the temperature of extremities of animals under cold conditions were lowered (result of reduced blood flow) in order to minimise further loss of body heat into the environment (Mogg and Plollitt, 1992), thereby maintaining core body temperature.

Correlations between RTEMP and the ear base measurements were high. Studies on goats and sheep (Goodwin, 1998) compared tympanic infrared with rectal temperature and reported high correlations between these two regions. Likewise, studies on humans (Van Staaij *et al.*, 2003) have also shown high correlations (r=0.83 to 0.85) between the tympanic membrane and rectal temperatures. Our strategy was comparable to that of Hughes *et al*. (1985) who measured the temperature of the area behind the ear lobes and rectal temperature of children and also found good correlations between the two measurements.

The correlation between RTEMP and AVCRL was 0.75. Body surface temperature was less associated with core body temperature than temperatures recorded at the base of the ears, but the correlations were still strong.

Preweaning mortality

The overall preweaning mortality for all piglets born alive in this study was higher (15.4%) than the annual average preweaning mortality rate (13.9%) in Australian pig farms (APL, 2009-2010), but still within the range of mortality rates reported in most commercial herds worldwide (Alonso-Spilsbury *et al.*, 2007). Sixty-one percent of these deaths occurred in the first 5 days of life, with 46% of deaths occurring in the first 48 h, in agreement with Dyck and Swierstra (1987). The main causes of death were crushing (46%) and starvation (32%), similar to reports by Lay *et al*. (2002) on causes of early piglet deaths in developed countries. Farrowing environment (Edwards, 2002) and animal genotype (Hellbrugge *et al.*, 2008) have also been associated with piglet mortality rates.

Relationships between temperature traits and mortality

Piglets were divided into five approximately equal sized groups based on RTEMP, BEAR_L, TEAR_L, and AVCRL. The percent mortality within each group is shown in Table 3. Except for when ranking was based on TEAR_L, the piglet's body temperature post-farrowing was always positively associated with its survival rate. Both body weight and rectal temperature, amongst other factors, have also been associated with piglet survival (Tabuaciri and Bunter, 2011).

Table 3. Number of piglets and mortality rates for animals grouped by recorded temperature with the corresponding mean birth weight.

Group	N	Temperature (°C)		Birth weight	Mortality (%)	
		Range	Mean	(kg)	Total	48hr
			RTEMP			
1	126	32.5-37.8	37.2±0.08	1.44±0.03	35	45
2	157	37.8-38.2	38.0±0.01	1.54±0.03	11	35
3	119	38.2-38.4	38.3±0.01	1.65±0.03	16	53
4	112	38.4-38.7	38.5±0.01	1.61±0.03	8	33
5	111	38.7-39.6	38.9±0.02	1.76±0.03	4	25
			BEAR_L			
1	117	30.8-37.1	36.1±0.11	1.49±0.04	27	53
2	99	37.1-37.8	37.4±0.02	1.55±0.03	13	38
3	113	37.8-38.4	38.0±0.01	1.66±0.03	15	47
4	115	38.4-39.2	38.7±0.02	1.62±0.03	10	36
5	95	39.2-41.8	39.8±0.06	1.64±0.03	12	18
			TEAR_L			
1	122	26.6-31.9	30.4±0.10	1.60±0.03	18	50
2	113	31.9-33.5	32.6±0.05	1.55±0.03	21	50
3	116	33.5-35.2	34.2±0.04	1.55±0.03	16	37
4	115	35.2-37.0	36.1±0.05	1.64±0.03	11	54
5	109	37.0-41.5	38.2±0.09	1.62±0.03	13	33
			AVCRL			
1	153	30.8-36.9	36.1±0.07	1.54±0.03	24	57
2	111	36.9-37.3	37.1±0.01	1.60±0.03	17	26
3	127	37.3-37.9	37.6±0.01	1.58±0.03	9	58
4	118	37.9-38.7	38.3±0.02	1.63±0.03	12	64
5	119	38.7-41.8	39.5±0.07	1.61±0.03	13	20

A relatively large proportion (18 to 35%) of all recorded deaths occurred in the groups of piglets recorded with the lowest temperatures, and around 50 to 60% of these piglets died within the first 48 h *post partum*, in agreement with Andersen *et al*. (2005). The majority of these deaths were attributed to crushing, suggesting that early detection of sub-optimal piglets after birth was important in reducing preweaning deaths. The lack of association observed between TEAR_L and birth weight, mortality, or rectal temperature (Table 2) did not support the use of temperature assessed only at extremities (such as ear tips and nose) as reliable indicators of mortality risk to piglets.

Dealing with at risk piglets

Intervention is more likely to be given to shivering piglets. This would include at a minimum, placing the piglet under the heater or at the udder to improve its chance of survival. In this study, 34% of shivering piglets did not survive. Therefore, shivering is a relatively reliable indicator of lower body temperature and a good cue to initiate intervention.

Table 4. Mean temperatures of piglets recorded post-farrowing with and without shivering thermogenesis.

Shivering	N	RTEMP (°C)	BEAR_L (°C)	TEAR_L (°C)	AVCRL (°C)
Present	58	37.5±0.18[a]	37.2±0.18[a]	32.5±0.29[a]	36.9±0.17[a]
Absent	567	38.2±0.02[b]	38.1±0.06[b]	34.4±0.12[b]	37.7±0.05[b]

Rows with different superscripts are significantly different (P<0.05).

Mean temperatures of shivering and non-shivering piglets were significantly (P<0.05) different for RTEMP and for IR values across the three anatomical regions (Table 4). Shivering, therefore, could be used as a warning for stockmen to provide intervention, but not all hypothermic piglets would show shivering (Herpin *et al.*, 2002; Lossec *et al.*, 1998). Of the piglets that did not show any shivering (n=567), 13% (n=73) died before weaning, and 7 to 24% were colder than the average temperature for shivering piglets (Table 4).

Conclusions

Infrared thermography is an effective tool for identifying hypothermic piglets and a viable alternative to measuring the actual core body temperature of newborn piglets. While intervention should be provided to all shivering piglets, those with low IR body temperature within 24 h after farrowing should also be given further attention. Future work should investigate the effects of simple management practices such as drying and placing piglets near the udder or heater on the survival rate of at risk piglets with respect to the IR data.

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References

Alonso-Spilsbury, M., Ramirez-Necoechea, R., Gonzalez-Lozano, M., Mota-Rojas, D. &Trujillo-Ortega, M. E. (2007). Piglet survival in early lactation: A review. Journal of Animal and Veterinary Advances 6(1): 76-86.

Andersen, I. L., Berg, S. &Boe, K. E. (2005). Crushing of piglets by the mother sow (Sus scrofa) - purely accidental or a poor mother? Applied Animal Behaviour Science 93: 229-243.

APL (2009-2010).Australian Pig Annual 2009 - 2010. In Australian Pork Limited, 1-74 Deakin, ACT, Australia.

Blokhuis, H. J., Jones, R. B., Geers, R., Miele, M. &Veissier, I. (2003). Measuring and monitoring animal welfare: transparency in the food product quality chain. Animal Welfare 12: 445-455.

Casella, J., Noguera, J. L., Varona, L., Sanchez, A., Arque, M. &Piedrafita, J. (2004). Viability of Iberian x Meishan F2 newborn pigs. II. Survival analysis up to weaning. Journal of Animal Science 82: 1925-1930.

Dyck, G. W. &Swierstra, E. E. (1987). Causes of piglet deaths from birth to weaning. Canadian Journal of Animal Science 67: 543-547.

Edwards, S. A. (2002). Perinatal mortality in the pig: environmental or physiological solutions? Livestock Production Science 78: 3-12.

Gloster, J., Ebert, K., Gubbins, S., Bashiruddin, J. &Paton, D. J. (2011). Normal variation in thermal radiated temperature in cattle: implications for foot-and-mouth disease detection. BMC Veterinary Research 7(73): 1-10.

Goodwin, S. D. (1998). Comparison of body temperatures of goats, horses, and sheep measured with a tympanic infrared thermometer, an implantable microchip transponder, and a rectal thermometer. Contemporary Topics in Laboratory Animal Science 37(3): 51-55.

Hellbrugge, B., Tolle, K.-H., Bennewitz, J., Henze, C., Presuhn, U. &Krieter, J. (2008). Genetic aspects regarding piglet losses and the maternal behaviour of sows. Part 1. Genetic analysis of piglet mortality and fertility traits in pigs. Animal 2(9): 1273-1280.

Herpin, P., Damon, M. &Le Dividich, J. (2002). Development of thermoregulation and neonatal survival in pigs. Livestock Production Science 78(1): 25-45.

Hughes, W. T., Patterson, G. G., Thornton, D., Williams, B. J., Lott, L. &Dodge, R. (1985). Detection of fever with infrared thermometry - A feasibility study. The Journal of Infectious Diseases 152(2): 301-306.

Lay, D. C. J., Matteri, R. L., Carrol, J. A., Fangman, T. J. &Safranski, T. J. (2002). Preweaning survival in swine. Journal of Animal Science 80(E. Suppl.1): E74-E86.

Lossec, G., Herpin, P. &Le Dividich, J. (1998). Thermoregulatory responses of the newborn pig during experimentally induced hypothermia and rewarming. Experimental Physiology 83: 667-678.

Lunstra, D. D. &Coulter, G. H. (1997). Relationship between scrotal infrared temperature patterns and natural-mating fertility in beef bulls. Journal of Animal Science 75: 767-774.

Mogg, K. C. &Plollitt, C. C. (1992). Hoof and distal limb surface temperature in the normal pony under constant and changing ambient temperatures. Equine Veterinary Journal 24(2): 134-139.

Palmer, S. E. (1981). Use of the portable infrared thermometer as a means of measuring limb surface temperature in the horse. American Journal of Veterinary Research 42(1): 105-108.

Radostits, O. M., Gay, C. C., Blood, D., C &Hinchcliff, K. W. (2000). Diseases of the newborn. In Veterinary Medicine: A textbook of the diseases of cattle, sheep, pigs, goats and horses. Philadelphia: Elsevier.

Rainwater-Lovett, K., Pacheco, J. M., Packer, C. &Rodriguez, L. L. (2009). Detection of foot-and-mouth disease virus infected cattle using infrared thermography. The Veterinary Journal 180(3): 317-324.

Schaefer, A. L., Cook, N., Tessaro, S. V., Deregt, D., Desroches, G., Dubeski, P. L., Tong, A. K. W. &Godson, D. L. (2004). Early detection and prediction of infection using infrared thermography. Canadian Journal of Animal Science: 73-80.

Schaefer, A. L., Jones, S. D. M., Murray, A. C., Sather, A. P. &Tong, A. K. W. (1989). Infrared thermography of pigs with known genotypes for stress susceptibility in relation to pork quality. Canadian Journal of Animal Science 69: 491-495.

Tabuaciri, P. (2012).Improving preweaning survival of piglets through genetic selection and management. In Animal Genetics and Breeding Unit, 197 Armidale, NSW, Australia: PhD thesis. Animal Genetics and Breeding Unit, University of New England, Armidale, NSW, Australia.

Tabuaciri, P. &Bunter, K. L. (2011).Piglet attributes at birth can influence survival. In 13th Biennial Conference of the Australian Pig Science Association (APSA), 246 (Ed R. J. Van Barneveld). Adelaide, SA, Australia: Australian Pig Science Association.

Van Staaij, B. K., Rovers, M. M., Schilder, A. G. &Hoes, A. W. (2003). Accuracy and feasibility of daily infrared tympanic membrane temperature measurements in the identification of fever in children (Abstract). International Journal of Pediatric Otorhinolaryngology 67(10): 1091-1097.

Yaron, M., Lowenstein, S. R. &Koziol-McLain, J. (1995). Measuring the accuracy of the infrared tympanic thermometer: Correlation does not signify agreement. The Journal of Emergency Medicine 13(5): 617-621.