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Original Article

Prediction of calving time in Holstein dairy cows by monitoring the ventral tail base surface temperature

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ABSTRACT

Dystocia adversely affects the health of calves and their dams. The aim of this study was to determine whether the ventral tail base surface temperature (ST) could be used to predict calving time in dairy cows. Pregnant Holstein cows were enrolled during the warm season (daily average air temperature 10–20 °C; $n = 13$) and cool season (daily average air temperature < 10 °C; $n = 22$) in Hokkaido, Japan, and a wearable wireless ST sensor was attached to the surface of the ventral tail base of each cow 9–12 days before the predicted calving date. The ventral tail base ST was measured every 2 min until 24 h after calving. Hourly maximum ventral tail base ST values were used in the analysis and changes in ventral tail base ST were expressed as residual temperatures (RTs) to exclude any circadian effects using the formula: RT = actual ST − mean ST for the same hour on the previous 3 days. In both seasons, there was a continual decrease in ventral tail base RT from approximately 24 h before calving compared with the control ventral tail base RT from 120 to 97 h before calving. The areas under the receiver operating characteristic curves (ROC-AUCs) for ventral tail base RT as a predictor of calving were 0.88–0.95. ROC-AUCs as a predictor of calving within 24 h were higher in the warm season than in the cool season. These findings demonstrate that calving time in dairy cows can be predicted by monitoring ventral tail base ST with a wearable wireless sensor, but seasonal variability affects the accuracy of prediction of calving time.
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Introduction

Dystocia in dairy cows is an important issue for dairy farmers because it adversely affects the health of calves and their dams (Lombard et al., 2007). The frequency of dystocia is significantly higher in dairy cows (6.2%) than in beef cows (4.4%) (De Amicis et al., 2018). In intensive herds, human presence at the time of calving provides the opportunity for assistance during difficult calving situations; it has been suggested that assistance should be provided within 65 min of the appearance of the feet of the foetus to maximise the survivability of both the calf and dam (Schuenemann et al., 2011). Although the number of dairy farms has decreased in the past few decades, the average size of dairy farms has increased continuously in most developed countries (Barkema et al., 2015), allowing less time to be allocated to the supervision of individual cows. Therefore, an automated device that can accurately predict calving time would be valuable in helping to reduce the impact of dystocia on dairy cows.

Several clinical signs are observed during the 72 h before calving (Saint-Dizier and Chastant-Maillard, 2015), with body temperature in particular showing a marked decrease. It has been reported that rectal (Burfeind et al., 2011), vaginal (Aoki et al., 2005; Burfeind et al., 2011; Ouellet et al., 2016; Ricci et al., 2018), ruminal (Cooper-Prado et al., 2011; Costa et al., 2016; Kovács et al., 2017), and aural (Rutten et al., 2017) temperatures can be used to predict calving time. On-farm vaginal temperature (VT) sensors for prediction of calving time have been marketed (Saint-Dizier and Chastant-Maillard, 2015). A decrease in VT of 0.1–0.3 °C can be used to predict parturition within the next 24 h, with a sensitivity (Se) of 62–74% and a specificity (Sp) of 74–87% (Burfeind et al., 2011; Ouellet et al., 2016; Ricci et al., 2018). However, this approach has two limitations: (1) the risk of mild inflammation in the vagina associated with placement of the sensor (Ricci et al., 2018); and (2) the possibility of loss or damage to the sensor due to displacement from the vagina during foetal delivery. Moreover, displacement of the sensor from the vagina during parturition renders it difficult to

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monitor post-partum body temperature continuously after parturition, whereas post-partum body temperature can be used to monitor subsequent disease in dairy cows (Smith and Risco, 2005). Therefore, an alternative sensor that could monitor the body temperature of dairy cows throughout the peripartum period would be useful on farms.

A wearable wireless sensor has been developed to measure the ventral tail base surface temperature (ST) in calves (Nogami et al., 2013, 2014). This approach is potentially less stressful to the animal and less invasive than measuring VT, and the sensor would also be less likely to fall off during foetal delivery. Miura et al. (2017) demonstrated that a wearable wireless ST sensor can be used monitor the ventral tail base ST throughout the oestrous cycle and that there is a substantial change in temperature around the time that behavioural oestrus is expressed. However, the potential use of this technology for predicting calving time remains unclear.

The aim of this study was to investigate whether a wearable wireless ventral tail base ST sensor can be used to predict calving time in dairy cows. Since it has been shown that there is variation in the circadian rhythm of ventral tail base ST between seasons (Miura et al., 2017), we examined peripartum changes in ventral tail base ST during the warm and cool seasons, and determined the accuracy of using a decrease in ventral tail base ST to predict calving time in each season.

Materials and methods

Study location and animals

This study was conducted at the Konsen Agricultural Experiment Station, Nakashibetsu, Hokkaido, Japan (43.5 N, 145.0 E), which had a milking herd of approximately 80 Holstein cows producing an average of 27.1 kg of milk per cow per day. All of the procedures employed in this study were approved by the Animal Care Committee for Laboratory Animals of the Konsen Agricultural Experiment Station (permission number 20156401; date of approval 7 April 2015). Thirty-five pregnant Holstein cows (average parity ± standard deviation, SD, 1.3 ± 1.3) were enrolled in the study from September 2015 to September 2016. They were housed in a tie-stall barn under the normal management programme of the Konsen Agricultural Experiment Station and were fed a total mixed ration diet consisting of grass silage, wheat straw and concentrate, with free access to water and a salt-based mineral supplement. The cows were moved to the maternity pen (300 cm × 300–600 cm) when they showed signs of onset of parturition (i.e. restlessness, relaxation of the sacrosciatic ligament, leakage of milk). The calving time for each cow was determined visually and defined as the time when the foetus was expelled from the vagina. None of the tested cows had dystocia and all had a single birth.

Ventral tail base surface temperature

The ST of the ventral tail base in each cow was measured with a sensor, as described by Miura et al. (2017). The sensor was 25.0 mm × 25.0 mm × 9.6 mm, weighed 7.7 g when a CR2032 battery (3.0 g) was inserted, and was housed inside a soft cover measuring 29.0 mm × 29.0 mm × 11.6 mm (45.0 mm × 45.0 mm on the upper side). The sensor was attached to the surface of the ventral tail base 9–12 days before the predicted calving date. The sensor was wrapped with an elastic medical bandage (SRPH50; Nichiban Company) and surrounded with a hook and loop fastener to stabilise its position. It was also suspended from the back of the animal by elastic webbing with hook and loop fasteners and then wrapped with an elastic medical bandage (SRPH75; Nichiban Company) to cover the sensor, fastener and elastic webbing. The ventral tail base ST was measured every 2 min until 24 h after calving. The ambient air temperature and humidity during the experimental period were also recorded every hour using a data logger (TR-72wf-H; T&D Corporation).

Experimental design

A total of 317,853 ventral tail base ST measurements were obtained from 35 cows from the time of sensor attachment to 24 h after calving (mean reception rate of ventral tail base ST data = 98.2 ± 1.8%). Hourly maximum ventral tail base ST values were used in the analysis and changes in ST were expressed as residual temperatures (RTs) using the formula: RT = actual ST − mean ST for the same hour on the previous 3 days; RTs were used to eliminate any circadian effects from the data, based on the study by Miura et al. (2017), which indicated no significant differences in mean ventral tail base RT according to season and time of the day, suggesting no obvious effects of the circadian rhythm. The period during which the daily average air temperature was 10–20 °C was defined as the 'warm season', while the period during which the daily average air temperature was < 10 °C was defined as the 'cool season', considering the mean daily average air temperature (10.1 °C) during the test period (from September 2015 to September 2016). Mean daily average air temperatures during the warm and cool seasons were 13.7 ± 2.4 °C (10.5–17.6 °C) and 4.4 ± 3.0 °C (−0.1 to 9.1 °C), respectively. Changes in ventral tail base ST and RT during the periparturient period were investigated first in the warm (n = 13) and cool (n = 22) seasons. The diagnostic performance and cut-off points of ventral tail base RT for predicting calving time were determined and compared between the two seasons.

Statistical analysis

The ventral tail base ST and RT values obtained from 96 h before calving to 24 h after calving were compared with the mean values obtained from 120 to 97 h before calving as a control using the non-parametric Steel test in JMP 11.0 (SAS Institute). The diagnostic performance and cut-off point of a decrease in ventral tail base RT for predicting calving within the next 6, 12, 18 and 24 h were established using receiver operating characteristics (ROC) analysis of the 120 h before calving. The cut-off point for each indicator was defined as the threshold that optimised both sensitivity (Se) and specificity (Sp) for predicting calving time. Ventral tail base RT was included as a continuous variable and the occurrence of calving within 6, 12, 18 and 24 h was included as the classification variable. Since the indicators were pooled into 1 h periods, there were 6, 12, 18 and 24 positive events per cow, which were defined as the occurrence of calving within 6, 12, 18 and 24 h, respectively. A predicted calving time was considered when the ventral tail base RT was less than or equal to the cut-off point. Se, Sp and predictive values, along with 95% confidence intervals, for the prediction of calving time for each cut-off point were calculated. Se was defined as the proportion of positive events (occurrence of calving within 6, 12, 18 and 24 h) that were correctly predicted by the test (calving correctly predicted/total calving events), while Sp was defined as the proportion of negative events (absence of calving within 6, 12, 18 and 24 h) that were correctly diagnosed as being negative by the test (absence of calving correctly predicted/total of calving absences). The positive (or negative) predictive values were thus defined as the proportion of events with a positive (or negative) prediction of calving that resulted in calving (or no calving) within the expected time interval. The area under the ROC curve (ROC-AUC) was compared for the two resulting ROC curves using the unpaired DeLong's test in R software version 3.4.0 for Windows. In all analyses, a P value < 0.05 was considered to be statistically significant.

Results

Environmental conditions

The mean ambient air temperatures and temperature-humidity index during the experimental period were 13.6 ± 2.4 °C and 56.7 ± 3.8 °C in the warm season, and 4.6 ± 2.9 °C and 42.4 ± 4.9 °C in the cool season, respectively.

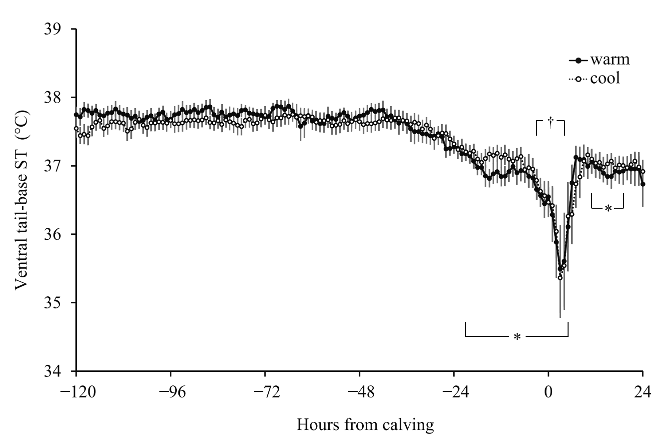

Fig. 1. Mean (± standard error) ventral tail base surface temperatures (STs) in Holstein dairy cows around calving. * and † indicate a significant difference compared with the average control ST from 120 to 97 h before calving in the warm and cool seasons, respectively (P < 0.05).

Table 1
Ventral tail base surface temperature (ST) and residual temperature (RT) of dairy cows at each landmark time point before calving in the warm and cool seasons in Japan.

Time before calving	ST (°C)		RT[a] (°C)	
	Warm	Cool	Warm	Cool
Control[b]	37.7 ± 0.28 (37.3 to 38.3)	37.6 ± 0.52 (36.8 to 39.1)	0.02 ± 0.14** (−0.20 to 0.27)	0.14 ± 0.17 (−0.17 to 0.41)
24 h	37.3 ± 0.36 (36.8 to 37.9)	37.3 ± 0.58 (36.2 to 38.9)	−0.43 ± 0.34 (−0.83 to 0.23)	−0.35 ± 0.40 (−1.03 to 0.27)
18 h	37.0 ± 0.41 (36.2 to 37.6)	37.1 ± 0.55 (36.1 to 38.6)	−0.86 ± 0.27* (−1.43 to 0.50)	−0.59 ± 0.43 (−1.40 to 0.23)
12 h	36.8 ± 0.49 (35.8 to 37.6)	37.1 ± 0.71 (34.9 to 38.6)	−0.77 ± 0.36 (−1.33 to 0.20)	−0.55 ± 0.49 (−2.37 to 0.17)
6 h	36.9 ± 0.54 (35.6 to 37.6)	36.9 ± 0.88 (33.9 to 38.6)	−0.70 ± 0.42 (−1.50 to 0.10)	−0.62 ± 0.48 (−2.37 to 0.17)
0 h	36.5 ± 0.81 (35.0 to 37.7)	36.5 ± 1.02 (33.4 to 38.8)	−1.03 ± 0.73 (−2.57 to −0.20)	−1.09 ± 0.89 (−4.33 to 0.00)

Significant differences between the warm and cool seasons are indicated by * ($P < 0.10$) and ** ($P < 0.05$). Values are means ± standard deviations (with minimum to maximum values in parentheses).
[a] Residual temperature = Actual body surface temperature – Mean body surface temperature for the same hour on the previous 3 days.
[b] Control: mean values from 120 to 97 h before calving.

Changes in body surface temperature and residual temperature during calving

Changes in ventral tail base ST around calving time are shown in Fig. 1. In both seasons, ventral tail base ST began to decline approximately 36 h before calving, became constant approximately 18 h before calving and then declined again approximately 6 h before calving. In the warm season, the ventral tail base STs from 21 to 0 h before calving were significantly lower than the control ventral tail base STs from 120 to 97 h before calving ($P < 0.05$). However, in the cool season, there was a continual significant decrease in ventral tail base ST from 3 h before calving until the time of parturition ($P < 0.05$). The changes in ventral tail base RT that occurred around calving are shown in Fig. 2. In the warm and cool seasons, there was a continual significant decrease in ventral tail base RT from 23 and 25 h before calving, respectively, until calving in comparison with the control ventral tail base RT ($P < 0.05$).

The ventral tail base ST and RT values at each landmark time point before calving in the warm and cool seasons are shown in Table 1. There was no significant difference in ventral tail base ST between seasons. However, the mean ventral tail base RT during the control period was significantly lower in the warm season than in the cool season ($P < 0.05$).

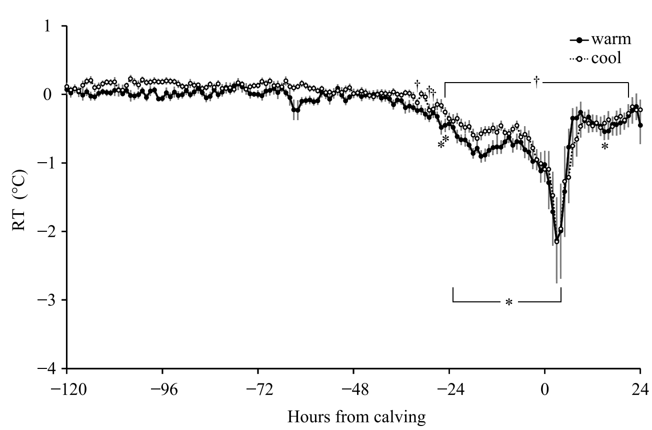

Fig. 2. Mean (± standard error) ventral tail base residual temperatures (RTs) in Holstein dairy cows around calving. * and † indicate a significant difference compared with the average control RT from 120 to 97 h before calving in the warm and cool seasons, respectively ($P < 0.05$).

Performance of residual temperature as a predictor of calving

Performance testing showed that the optimal cut-off point of the ventral tail base RT as a predictor of calving within 6, 12, 18 and 24 h was lower in the warm season than in the cool season (Table 2). The ROC curves for ventral tail base RT as a predictor of calving within 6, 12, 18 and 24 h are shown in Fig. 3. All ROC-AUCs were in the range 0.88–0.95, but were significantly higher in the warm season than in the cool season for ventral tail base RT as a predictor of calving within 18 and 24 h ($P < 0.05$).

Discussion

In this study, we examined whether a wearable wireless sensor that measures the ventral tail base ST can be used to predict calving time in Holstein dairy cows. The ventral tail base ST decreased by 0.6–0.9 °C 18 h before calving, which is slightly greater than the

Table 2
Performance testing of the optimal cut-off point of ventral tail base residual temperature as a predictor of calving within 6, 12, 18, and 24 h.

Prediction time	Performance[a]	Season	
		Warm	Cool
6 h	Cut-off point[b]	−0.36 °C	−0.28 °C
	Se (%)	90 (79–96)	83 (76–91)
	Sp (%)	79 (76–88)	82 (76–87)
	+PV (%)	19 (16–27)	20 (16–24)
	−PV (%)	99 (99–100)	99 (98–99)
12 h	Cut-off point	−0.36 °C	−0.28 °C
	Se (%)	90 (84–94)	84 (78–89)
	Sp (%)	82 (80–84)	85 (82–89)
	+PV (%)	35 (32–39)	38 (34–45)
	−PV (%)	99 (98–99)	98 (97–98)
18 h	Cut-off point	−0.36 °C	−0.26 °C
	Se (%)	92 (88–95)	83 (78–87)
	Sp (%)	87 (85–90)	88 (84–92)
	+PV (%)	55 (51–61)	56 (49–65)
	−PV (%)	98 (98–99)	97 (96–97)
24 h	Cut-off point	−0.36 °C	−0.22 °C
	Se (%)	89 (85–92)	80 (75–84)
	Sp (%)	91 (89–93)	89 (85–92)
	+PV (%)	71 (67–75)	65 (58–71)
	−PV (%)	97 (96–98)	95 (94–96)

Residual temperature = Actual body surface temperature – Mean body surface temperature for the same hour on the previous 3 days. Values are means (with the 95% confidence interval in parentheses).
[a] Performance: Se, sensitivity; Sp, specificity; +PV, positive predictive value; −PV, negative predictive value.
[b] Cut-off point: Threshold calculated for each indicator that optimises both Se and Sp for predicting calving.

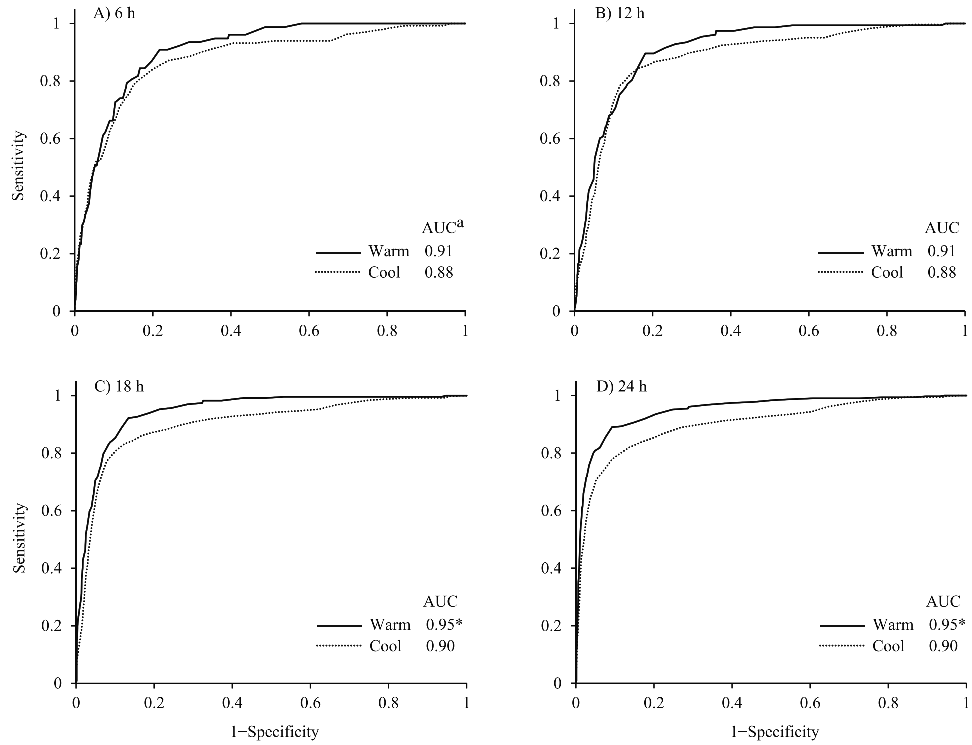

Fig. 3. Receiver-operating characteristics (ROC) curves for residual temperature (RT) as a predictor of calving within: (A) 6 h; (B) 12 h; (C) 18 h; and (D) 24 h in the warm and cool seasons. [a] AUC, area under the ROC curve. * Significant difference in AUC between the warm and cool seasons ($P < 0.05$).

decrease of 0.4–0.7 °C in vaginal temperature observed previously (Burfeind et al., 2011; Ouellet et al., 2016). It has been suggested that a decrease in body temperature in the immediate prepartum period is associated with the maternal plasma progesterone concentration (Costa et al., 2016). However, unlike VT, which increases in the last few hours before calving (Burfeind et al., 2011), the ST of the ventral tail base decreased further at approximately 6 h before calving. Therefore, it is reasonable to assume that the decrease in ventral tail base ST that occurs immediately before calving is due to a decrease in blood flow to the tail as a result of the foetus placing pressure on the blood vessels (Walls and Jacobson, 1970).

The decrease in ventral tail base temperature that was observed before calving occurred later in the cool season than in the warm season for the ST, but at similar times in both seasons for the RT. Similarly, Miura et al. (2017) demonstrated that variations in air temperature affect actual values and fluctuations (circadian rhythms) in ventral tail base ST values, but not RT values. However, the level of decrease in ventral tail base RT at approximately 18 h before calving was greater in the warm season than in the cool season, possibly due to differences in mechanisms of regulation of body temperature that are used under different ambient temperatures; in cold environments, heat production increases to prevent the body temperature from decreasing (Young, 1983). Since the present study was conducted in a cool region where the average daily temperature in August in the past 5 years has been < 20 °C (Japan Meteorological Agency[1]), we were unable to acquire data during the hot season. Future studies are required to examine changes in ventral tail base ST values that occur around calving during the hot season.

Decreases in ventral tail base RT could be used to distinguish between cows that had and had not calved within 6, 12, 18 and 24 h. The AUC values for these time points ranged from 0.88 to 0.95, which were similar to the ROC-AUC for VT predicting calving time within the next 24 h (Burfeind et al., 2011; Ouellet et al., 2016; Ricci et al., 2018). Therefore, the ventral tail base ST should be an equivalent index to VT for predicting calving time. Prediction of calving within the next 18 and 24 h was more accurate in the warm season than in the cool season, and the cut-off point was also lower in the warm season than in the cool season. The next step is to develop a system that outputs calving predictions in real time, taking into account these seasonal differences.

In the present study, we targeted only natural calving without assistance. Kovács et al. (2017) indicated that a decrease in ruminal temperature before calving occurs 12 h earlier in cows with dystocia cows than in eutocic cows. Therefore, it is likely that changes in ventral tail base ST before calving will also be different between dystocic and eutocic cows. Unlike vaginal sensors, ventral tail base ST sensors do not always fall off when the foetus is delivered and so can continue to be worn after delivery. Therefore, this technology may also have an application in post-partum body temperature monitoring, which is important for the management of disease in dairy cows (Smith and Risco, 2005).

Conclusions

A continual decrease in ventral tail base RT until calving occurred from approximately 24 h before calving in both the warm and cool seasons. The calving time in dairy cows can be predicted within 24 h before calving by monitoring ventral tail base ST using a wearable wireless sensor. Although seasonal variability in the ventral tail base ST affected the accuracy of prediction of calving time, the performance of the sensor for prediction of calving using the RT was fairly accurate, regardless of the season. A future aim is to develop a system with an output for prediction of calving in real time, taking into account these seasonal differences.

[1] See: https://www.jma.go.jp/jma/indexe.html (accessed 19th August 2018).

Conflict of interest statement

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of this paper.

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