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Evaluation of a commercial intravaginal thermometer to predict calving in a Hungarian Holstein-Friesian dairy farm

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Abstract
In this study, the utility of a commercial intravaginal thermometer was evaluated as an automated method for the prediction of calving in a total of 257 healthy pregnant Holstein–Friesian female cattle. The accuracy and the sensitivity of predicting calving within 48 hr before calving were also evaluated. The intravaginal temperature changes from 72 hr before and up to calving were significantly ($p \le .001$) affected by parity, season (summer vs. autumn), the time of day (8 a.m. or 8 p.m.) and the 6-hr time intervals (38.19°C: first interval 0 to 6 hr before calving vs. 38.78°C: twelfth interval 66 to 72 hr before calving), while the gender ($p = .943$), and the weight of the calf ($p = .610$), twinning ($p = .300$), gestation length ($p = .186$), foetal presentation ($p = .123$), dystocia ($p = .197$) and retention of foetal membranes ($p = .253$) did not affect it significantly. The sensitivity of the SMS of expecting calving within 48 hr and the positive predictive value were 62.4% and 75%, respectively, while the sensitivity and the positive predictive value for the SMS of expulsion reached 100%. It can be concluded that the investigated thermometer is not able to predict calving within 48 hr accurately; however, imminent calving can be accurately alerted.

KEYWORDS
dairy cattle, intravaginal thermometer, prediction of calving

1 | INTRODUCTION

Prediction of the exact time of calving would be highly important especially in small farms where there are no assistants working in day and night shifts. It has been known for a long time that pre-calving decrease in body temperature can be used for prediction of calving (Ewbank, 1963; Graf & Petersen, 1953; Porterfield & Olson, 1957). Since then, several reports have confirmed the pre-calving decrease in vaginal temperature by using sensors inserted into the vagina after attaching to a modified controlled internal drug release device without progesterone at least 6 days before the expected time of calving retrospectively as temperature data could be downloaded only after calving (Burfeind, Suthar, Voigtsberger, Bonk, & Heuwieser, 2011; Miwa, Matsuyama, Nakamura, Noda, & Sakatani, 2019; Ouellet et al., 2016). By this way, the optimal cut-off points of decrease in vaginal temperature (≥0.3°C) one day before calving could be determined (Burfeind et al., 2011; Ouellet et al., 2016; Streyl et al., 2011).

Due to significant diurnal variations (by up to 0.5°C) in rectal and vaginal temperatures (lowest in the morning and highest in late afternoon), at least two temperature measurements are needed on a daily basis making temperature measurement impractical for calving prediction without converted them into automated signals (Aoki, Kimura, & Suzuki, 2005; Burfeind et al., 2011).

Digital data loggers have recently made the continuous recording possible, and via global system for mobile (GSM) technology, the actual vaginal temperature data can be received on mobile phones. Vaginal thermometers inform the user via SMS on its activation, the day-to-day changes in temperature, of the imminence of calving in the last 48 hr before calving and of the expulsion of the device (the onset of the second stage of labour).

There is paucity of information (Chanvallon, Leblay, Girardot, Daviere, & Lamy, 2012; Ricci et al., 2018) regarding the actual performance of those marketed devices used under field conditions; therefore, the aim of the present study was to evaluate the utility of an intravaginal thermometer as an automated method for prediction of calving in a Holstein–Friesian Hungarian dairy farm. The accuracy of predicting calving within 48 hr by sending a SMS was also evaluated.

2 | MATERIALS AND METHODS

The work was conducted in full compliance with the guidelines of the Animal Experimentation Committee (22.1/1606/003/2009, Budapest, Hungary).

2.1 | Housing, feeding and milking technology

Our study was conducted as part of a larger research project on metabolic, behavioural and physiological aspects of bovine parturition at the Prograg Agrárcentrum Ltd. in Ráckeresztúr, Lászlópuszta, Hungary, which has a herd of 900 Holstein–Friesian cattle.

From 28 days before the expected time of calving, preparturient heifers and cows were housed in a precalving group pen (measuring 45 × 25 m), which included 50 to 60 animals and was bedded with deep straw. If calving assistance was needed, there was an individual maternity pen (measuring 4 × 5 m) where the straw was changed after each assistance. Before calving, cows were fed a prepartum total mixed ration (TMR) ad libitum containing a dietary forage-to-concentrate ratio of 78:22 on a dry-matter (DM) basis. After calving, cows were fed a post-partum TMR ad libitum with a 60:40 forage-to-concentrate ratio on a dry-matter basis as described previously (Kovács, Kézér, Ruff, & Szenci, 2016). Water was available ad libitum.

2.2 | Experimental groups and calving management

Five days before the expected date of calving (the mean duration of gestation for nulliparous and pluriparous cows calculated for a year basis (n = 927) before starting the experiment was 275.9 (*SD*: 5.8) days, healthy pregnant cows (n = 257 including 92 nulliparous heifers) being in the precalving group pen were randomly selected for the study. Parity ranged from 2 to 5 for pluriparous cows (mean ± *SD*: 2.9 ± 0.3). An intravaginal thermometer (Vel'Phone, Medria, Châteaugiron, France) was inserted into the vagina an average of 7.4 ± 5.4 days before calving. Depending on the body size of the animals, different appendage kits were used for heifers (turquoise) and pluriparous cows (white) as described previously (Choukeir et al., 2020). Twenty intravaginal thermometers were used in the present experiment. After equipping the thermometer with the flexible appendages, it was inserted into a vaginal applicator which was immersed into the povidone–iodine solution (Betadine®) for at least 2 min before cleansing and disinfecting the perineal area of the cow and gently inserting deep into the vagina. Location device was used to detect the expelled thermometers in the deep straw. After finding it, a soft brush was used to clean the thermometer and appendages which were disinfected and stored until the next usage in the blue trunk as recommended in the manual. The mean ± *SD* body condition scores using the 5-point scoring system (Hady, Domecq, & Kaneene, 1994) following calving were 3.1 ± 0.2 for heifers and 3.3 ± 0.2 for pluriparous cows, respectively. Once the thermometer had been placed into the vagina, the Vel'Phone sent information via SMS on its activation and the time (5–10 min) required for the temperature to rise above 36.4°C. From this time on, two daily reports sent at 8 a.m. and 8 p.m. providing the temperature measured in each animal during the half-hour prior to sending the SMS. 'Possible calving in 48 hr' was created when at least one of the two algorithms, while in case of 'Expected calving in 48 hr' SMS both algorithms crossed their triggering threshold over a period of 2 hr. According to the producers' user manual, the first algorithm calculates the absolute variation of the temperature that has dropped below 39°C after having previously risen above 39°C while the second algorithm calculates the relative variation of the temperature that has dropped close to 2°C after having risen close to 41°C. When a thermometer was expelled by the allantoic sac and observed its temperature falling below 36.0°C, an 'expulsion' SMS was sent. The onset of the second stage of labour was determined by this SMS for the cows. Forty-two cows were excluded from the later analysis because the thermometer was in the vagina for less than 3 days before its expulsion. Supervision of the dams during calving and the decision to move them into the maternity pen or to provide obstetrical assistance was made by the farm personnel (Kovács, Kézér, & Szenci, 2016).

2.3 | Obstetrical assistance and dystocia scoring

Prepartum behaviour of the animals was recorded with a closed-circuit camera system including two day/night outdoor network bullet cameras (Vivotek IP8331, VIVOTEK Inc., Taiwan) installed above the precalving group pen allowing the identification of the onset of calving restlessness, the appearance of the amniotic sac and the presence of dystocia.

Based on video recordings, the start of obstetrical assistance was considered when at least one person assisted the cow using a calving rope or a calf puller. Calving assistance by trained farm personnel was performed at the latest within 90 min after the appearance of the amniotic sac in the vulva as described previously by Kovács, Kézér, and Szenci (2016). Type of calving (single or twin calving), presentation of the calf (anterior or posterior), presence of dystocia (without or with obstetrical assistance), gender and weight of the calf, time of day (8 a.m. or 8 p.m.), season (summer with calvings in June, July and August vs. fall with calvings in September, October and November), parity (nulliparous or pluriparous cows), gestation length and the retained foetal membranes (RFM) diagnosed 12–24 hr after calving were also recorded.

2.4 | Statistical analysis

All statistical analyses were done with the Statistica Computer Software, version 13 (Tibco Software Inc., 2017). Analysis of raw data of temperature was performed by general linear models (GLM), and the following fixed effects were chosen: type of calving (single or twin calving), presentation of the calf (anterior or posterior), calving ease (dystocic or eutocic), gender of the calf, time of day (8 a.m. or 8 p.m.), season (summer with calving in June, July and August or fall with calving in September, October and November), parity (nulliparous or pluriparous cows) and RFM (absence or presence) diagnosed from 12 to 24 hr after calving. The last 72-hr temperature measurements were split into twelve 6-hr periods and used also as a fixed effect. Birthweight of the calf (with a mean value of 43.3 kg) and gestation length (with a mean value of 277.6 days) were considered as covariates.

The statistical significance of these effects was estimated by a backward elimination, taking into account what effects were eligible for removal. As a result, the *p*-value of each effect, as well as the least-squares mean (LSM) and standard error of mean (*SEM*), was presented according to significant effects. To measure eventually differences, the Tukey's post hoc test was used for temperatures.

The SMSs for the expected calving within 48 hr and for the expulsion were arranged as follows: correct-positive diagnosis (occurrence of calving within 48 hr or after expulsion), incorrect positive diagnosis (calving did not occur within 48 hr) and incorrect negative diagnosis (calving was not predicted at all). From these values, sensitivity [$100 \times a/(a + c)$] and the positive predictive value of the SMS messages [$100 \times a/(a + b)$] were calculated as described previously by Szenci et al. (1998).

3 | RESULTS

None of the thermometers were lost during the trial. Intravaginal temperature was not affected by the gender ($p = .943$), the birthweight of the calf ($p = .610$), twinning ($p = .300$), gestation length ($p = .186$), foetal presentation ($p = .123$), calving ease ($p = .197$) and RFM ($p = .253$), while parity, time of day (8 a.m. vs. 8 p.m.), season (summer vs. autumn), (Table 1) and the 6-hr time intervals (38.2°C: first interval between 0 and 6 hr before calving vs. 38.8°C: twelfth interval between 66 and 72 hr before calving) significantly ($p \le .001$) affected it (Table 2).

After SMS messages of possible calving within 48 hr 68.5% of the cows, while after SMS messages of expected calving within 48 hr 58.8% of the cows calved within 48 hr. It is important to mention that among the 50 correct-positive diagnoses, 15 cows were

TABLE 1 Vaginal temperatures are significantly affected by the following variables

Effect	Number of observations	Vaginal temperature (°C) LSM	*SEM*
Time of day		$p < .001$	
8 a.m. (morning)	651	38.28^{a}	0.0180
8 p.m. (evening)	690	38.82^{b}	0.0177
Season		$p = .001$	
Summer	558	38.59^{b}	0.0199
Fall	783	38.51^{a}	0.0160
Parity		$p < .001$	
Nulliparous	324	38.48^{a}	0.0238
Pluriparous	1,017	38.62^{b}	0.0131

Abbreviations: LSM, least square mean; *SEM*, standard error of the mean.

TABLE 2 Vaginal temperatures are significantly ($p < .001$) affected by the 6-hr time intervals

6-hr time intervals	Number of observations	Vaginal temperature (°C) LSM	*SEM*
12th (66 to 72 hr before calving)	93	38.78^{d}	0.0441
11^{th}	103	38.68^{cd}	0.0417
10^{th}	95	38.72^{cd}	0.0435
9^{th}	113	38.74^{cd}	0.0399
8^{th}	103	38.71^{cd}	0.0418
7^{th}	118	38.59^{bcd}	0.0392
6^{th}	110	38.57^{bcd}	0.0406
5^{th}	121	38.61^{bcd}	0.0386
4^{th}	112	38.45^{bc}	0.0402
3^{rd}	122	38.37^{ab}	0.0384
2^{nd}	119	38.21^{a}	0.0390
1st (0–6 hr before calving)	132	38.19^{a}	0.0370

Note: a, b, c, d – different letters mean significant ($p < .05$) differences (Tukey's post hoc test).
Abbreviations: LSM, least square mean; *SEM*, standard error of the mean.

already correctly predicted by the first SMS messages. Although the expulsion SMS messages were sent in each case (Table 3), thermometers did not generate any SMS messages before the onset of the parturition process in 37 cases (17.2%). The mean (±*SD*) duration between SMS message of possible calving within 48 hr and calving was 139 ± 117 hr (min: 15 hr, max: 529 hr), while between expected calving within 48 hr and calving was 64 ± 83 hr (min: 2 hr, max: 428 hr), respectively. There were no two alarms during the first 12-hr period before calving.

4 | DISCUSSION

Several remote devices are available for dairy farmers to record decreases in body or vaginal temperatures for the prediction of the onset of calving. However, only a few authors reported on changes in vaginal temperature around calving in beef cattle based on Medria thermometers (Ricci et al., 2018) and dairy cows (Chanvallon et al., 2012).

The sensitivity of receiving the 'possible calving in 48 hr' SMS message was 40% (Chanvallon et al., 2012) while the sensitivity of the 'expected calving in 48 hr' SMS message was 82.9%, respectively. In contrast, our sensitivity results for possible and expected calvings in 48 hr SMS messages were only 21.1% and 62.4%, respectively, while the positive predictive value of the SMS messages was 10.3% and 75%, respectively. Sakatani et al. (2018) used another temperature sensor in 625 beef cattle which recorded the vaginal temperature every 5 min, and every 4 hr, the moving average temperature was calculated automatically. An alert (Alert 1) was issued when the temperature difference was higher than the threshold (0.4°C). The duration (mean + *SD*) between the alert and the beginning of the second stage of labour (broken of allantoic sac) was 21:59 + 7:07, and the sensitivity of this alert was 88.3%.

To increase the accuracy of measuring the vaginal temperature, Ricci et al. (2018) have suggested to use the intravaginal temperature 38.2°C as a cut-off value to predict calving within 24 hr because it can be more accurate (sensitivity: 86% vs. 66%) than a 0.21°C decrease during the last 24 hr before calving. Authors found similar changes to our findings as in their study the mean vaginal temperature decreased from 38.65 to 38.12°C between 48 and 60 hr and 0 to 12 hr before calving, respectively (data not given in Table 2).

According to Lammoglia et al. (1997), vaginal temperatures were not affected by the gender of the calf, and there was no diurnal variation in body temperature from 48 to 8 hr before calving in beef cows. Ricci et al. (2018) reported that parity, dystocia, season and length of gestation did not affect the vaginal temperature from 60 hr before and up to calving. According to our results, the vaginal temperature of dairy cows was significantly affected by parity, season (summer vs. autumn), time of day (8 a.m. vs. 8 p.m.) and the 6-hr time intervals, whereas gender, birthweight of the calf, twinning, gestation length, foetal presentation, dystocia and presence of RFM did not affect it significantly. The present results can be explained with a diurnal rhythm (up to 0.5°C) in the vaginal temperature during the last 120 hr before calving (Burfeind et al., 2011; Ouellet et al., 2016); hence, others did not confirm this precalving diurnal variation (Lammoglia et al., 1997; Ricci et al., 2018).

According to Chanvallon et al. (2012), the sensitivity of the thermometer to detect allantoic sac expulsion was 100% for both heifers and cows, which is consistent with our findings because no false alarms were detected during the trial. Similarly, no false alarm and no lack of alarm when using an intravaginal mechanical GSM device were recorded by Palombi et al. (2013). Sakatani et al. (2018) monitored 625 beef cattle, and in four cases, the sensors had fallen out together with the calf or they were malfunctioned and the sensitivity of predicting calving (Alert 2) with the appearance of the allantoic sac was 99.4%. It seems that the second stage of calving can be detected accurately by using intravaginal sensors either in dairy or in beef farms.

It is important to mention that the intravaginal thermometer did not induce any pathological clinical signs except for a minor discomfort shown by some heifers (Choukeir et al., 2020). In contrast, when the intravaginal device remained inside the vaginal canal in some cases up to 20 days, no adverse effects were reported, and the animals did not exhibit any discomfort or vaginal discharge (Palombi et al., 2013; Ricci et al., 2018; Sakatani et al., 2018).

TABLE 3 Accuracy of prediction of calving by an SMS message

Grouping and evaluation	SMS of possible calving within 48 hr (*n* = 215)	SMS of expecting calving within 48 hr (*n* = 215)	SMS of expulsion (*n* = 257)
Correct-positive diagnosis[a]	16	111	257
False-positive diagnosis[b]	60	67	–
False-negative diagnosis[c]	139	37	–
Sensitivity[d]	21.1	62.4	100
Positive predictive value[e]	10.3	75.0	100

[a]Occurrence of calving within 48 hr (*a*).
[b]Calving did not occur within 48 hr (*b*).
[c]Calving was not predicted at all (*c*).
[d]$100 \times a/(a + c)$.
[e]$100 \times a/(a + b)$.

Our recent findings have supported the benefits of the Vel'Phone calving monitoring system in terms of calving management and post-partum health because the risk of dystocia (Score > 1) was 1.9 times higher, the prevalence of stillbirth was 19.8 times higher, the risk of retained foetal membranes (RFM) was 2.8 times higher, and the risk of clinical metritis was 10.5 times higher in the control group than in the experimental group (Choukeir et al., 2020). By the authors' opinion, such smart sensor systems used in this study can support the routine reproductive management in a cost-effective manner in large-scale dairy farms where the 'farm blindness' phenomenon is usual (Mee, 2013).

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CONFLICT OF INTEREST

None of the authors have any conflict of interest to declare.

AUTHOR CONTRIBUTIONS

Choukeir, A.I. performed the experiment 'on field', analysed data and wrote the manuscript. Kovács, L. collaborated on the study design, performed the experiment 'on field' and revised the manuscript. Kézér, L.F., Buják, D., Szelényi, Z. and Abdelmegeid, M.K. collaborated in the experiment 'on-field'. Gáspárdy, A. collaborated in analysing data. Szenci, O. collaborated in the study design and revised the manuscript.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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