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Rumination time and reticuloruminal temperature as possible predictors of dystocia in dairy cows

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ABSTRACT

The objectives of this study were to explore changes of rumination time and reticuloruminal pH and temperature of dairy cows and heifers (means ± standard deviation; age = 5.8 ± 1.9; parity = 2.7 ± 1.4; body condition score = 3.2 ± 0.2) with eutocic (EUT, n = 10) and dystocic calving (DYS, n = 8). The recording period lasted from 3 d before calving until 7 d in milk. For the comparison of rumination time and reticuloruminal characteristics between groups, time to return to baseline (the time interval required to return to baseline from the delivery of the calf) and area under the curve (AUC; both for prepartum and postpartum periods) were calculated for each parameter. Rumination time decreased from baseline 28 h before calving both for EUT and DYS cows; after 20 h before calving, it decreased to 32.4 ± 2.3 and 13.2 ± 2.0 min/4 h between 8 and 4 h before delivery in EUT and DYS cows, respectively, and then it decreased below 10 and 5 min during the last 4 h before calving. Until 12 h after delivery, rumination time reached 42.6 ± 2.7 and 51.0 ± 3.1 min/4 h in DYS and EUT dams, respectively; however, AUC and time to return to baseline suggested lower rumination activity in DYS cows than in EUT dams for the 168-h postpartum observational period. Reticuloruminal pH decreased from baseline 56 h before calving both for EUT and DYS cows, but did not differ between groups before delivery. Reticuloruminal pH showed a decreasing tendency and clear diurnal variation after calving for both EUT and DYS cows, with slightly higher AUC values in DYS cows. In DYS cows, reticuloruminal temperature decreased from baseline 32 h before calving by 0.23 ± 0.02°C, whereas in EUT cows such a decrease was found only 20 h before delivery (0.48 ± 0.05°C). The AUC of reticuloruminal temperature calculated for the prepartum period was greater in EUT cows than in DYS cows. During the first 4 h after calving, reticuloruminal temperature decreased from 39.68 ± 0.09 to 38.96 ± 0.10°C and from 39.80 ± 0.06 to 38.81 ± 0.08°C in EUT and DYS cows, respectively, and reached baseline levels after 35.4 ± 3.4 and 37.8 ± 4.2 h after calving in EUT and DYS cows, respectively. Based on our results, continuous monitoring of changes in rumination time and reticuloruminal temperature seems to be promising in the early detection of cows with a higher risk of dystocia. Depressed rumination activity of DYS cows after calving highlights the importance of the postpartum monitoring of cows experiencing difficulties at calving. The effect of dystocia on postpartum reticuloruminal pH was not pronounced.
Key words: rumination time, reticuloruminal temperature, reticuloruminal pH, dystocia, dairy cows

INTRODUCTION

Prediction of the onset of calving has great importance in decreasing neonatal losses and reducing the risk of health problems in the early postpartum period, which are crucial for maintaining profitable production on dairy farms. Behavioral changes (Huzzey et al., 2005; Jensen, 2012), and nonbehavioral external changes (Streyl et al., 2011) associated with parturition have been extensively studied in dairy cattle; however, the accurate prediction of the onset of calving is difficult due to the high variation between individuals (Rexha and Grunert, 1993; Hofmann et al., 2006). According to the recent findings of Kovács et al. (2015), assessment of cardiac autonomic activity is useful to predict calving in cases of unassisted births; however, obstetrical assistance at calving is commonly required in cases of difficult deliveries. As dystocia increases the prevalence of stillbirths (Bicalho et al., 2007) and causes intense pain to the dam (Laven et al., 2009), monitoring individuals predisposed to dystocia during the prepartum period is crucial in terms of both production and welfare.

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Current research evaluated behavioral predictors for normal and dystocic births. Miedema et al. (2011a) showed that cows with assisted calving had abdominal contractions earlier than cows with spontaneous calving, whereas others found that dystocic cows displayed restlessness earlier, raised their tail, and lay in lateral recumbency with the head rested for longer than cows calving naturally (Barrier et al., 2012). However, due to the large interindividual variation in behavioral changes associated with calving, additional physiological markers are increasingly applied to predict calving time. Schirmann et al. (2013) reported on automatic measurement of rumination time in the peripartal period using acoustic sensors based on the analysis of vocal signs. Results support that daily rumination time decreases during the last week before parturition (Soriani et al., 2012; Büchel and Sundrum, 2014). A recent study has proven that monitoring rumination time during the first 10 d of lactation allows the early detection of cows with a higher probability of developing health disorders observed during the first month of lactation (Calamari et al., 2014). To date, a lack of information exists on the associations between dystocia and rumination time around calving.

Besides rumination time, reticuloruminal pH is increasingly studied in dairy cows in the peripartal period. A reduction of rumination activity around parturition can result in SARA. A rumen pH below the level of 5.5 is commonly used as a threshold value for SARA (Oetzel et al., 1999; Plaizier et al., 2008). Although the introduction of wireless telemetry systems allowed the continuous monitoring of reticuloruminal pH under field conditions (Mottram et al., 2008; Phillips et al., 2010), changes in reticuloruminal pH have not been studied in relation with rumination time around parturition.

Precalving drops of body temperature are the result of regulation of the obligatory and facultative thermogenesis activated by thyroid hormones and catecholamines (Silva, 2006), as well as sexual hormones, which directly regulate facultative thermogenesis (Hampl et al., 2006). An early study reported that body temperature in bovines dropped by up to 1°C before the onset of parturition (Lammoglia et al., 1997), and others confirmed that this could be used as a predictor of calving (Burfeind et al., 2011; Cooper-Prado et al., 2011). However, the measurement of vaginal and rectal temperatures needs constant manual checks and represents a greater risk for the prevalence of lesions in these regions. The automatic recording of reticuloruminal temperature does not have these limitations (Sievers et al., 2004); moreover, according to Costa et al. (2016), reticuloruminal temperature is a good predictor of the approaching calving. To the best of our knowledge, the effect of dystocia on peripartal reticuloruminal temperature has not yet been studied.

The main objectives of our study were to explore the potential use of changes in rumination time and reticuloruminal temperature as possible predictors of dystocia and to identify differences in these parameters during the early postpartum period between cows having undergone difficult and normal calvings. Peripartal reticuloruminal pH was also studied.

MATERIALS AND METHODS

Animals, Housing, and Diet

The experiment was carried out at a large-scale dairy farm in Hungary (47°18′191″ N, 18°48′336″ E), with around 900 lactating Holstein-Friesian cows having a 38% prevalence rate of dystocia in the study year. The farm was visited for a 40-d period between October 10 and November 18, 2014 [temperature (average/minimum/maximum) = 3.5/−4.7/8.2°C].

Rumination time and reticuloruminal pH and temperature of 23 animals were monitored. All selected cows were inspected physically before the trial and 24, 48, and 168 h after calving. Animals that had suffered from acute or chronic health disorders (i.e., subclinical or clinical mastitis, lameness) before the trial were not included in the study. Cows with postpartum health disorders or injuries caused by parturition (i.e., clinical hypocalcemia, retained placenta, vulvovaginal laceration) were excluded (n = 3). Because of an unexpected early calving event, 2 animals were excluded due to the short precalving recording periods. Therefore, a total of 9 heifers and 9 multiparous cows (means ± SD; age = 5.8 ± 1.9; parity = 2.7 ± 1.4; BCS = 3.2 ± 0.2) were included in the study.

From 28 d before calving, dry cows were housed in a precalving group pen (measuring 35 × 20 m), which included 50 to 60 animals and was bedded with deep straw. Before calving, cows were fed a prepartum TMR ad libitum containing a dietary forage-to-concentrate ratio of 78:22 on a DM basis. After calving, cows were housed in postpartum pens, each including 4 animals. Cows were fed a postpartum TMR ad libitum with a 60:40 forage-to-concentrate ratio on a DM basis. Feed was provided twice daily at 0800 and 1600 h and water was available ad libitum. After calving, cows were milked twice daily at 0400 and 1400 h in a 4-stall herringbone milking parlor operated with DeLaval Control Valve bucket milking machines (DeLaval International AB, Tumba, Sweden) during the first 5 DIM. Following the first milking, dams were kept in postpartum pens including 3 to 4 animals until 3 DIM, then cows

were introduced to the fresh lactation group and milked twice daily at 0500 and 1500 h in a 2 × 28 stall parallel Bosmark milking parlor (Bosmark Kft., Biatorbágy, Hungary). The fresh lactation diet did not change within the first 15 DIM.

Rumination Activity

Rumination time was continuously recorded from 3 d before calving until 7 DIM using the Ruminact acoustic biotelemetry system (SCR Engineers Ltd., Netanya, Israel), which was validated for the measurement of rumination activity of dairy cows (Schirmann et al., 2009). The system consisted of rumination sensors, stationary readers, and software for processing the electronic data (Data Flow software, SCR Engineers Ltd.). The sensor consists of a neck collar with a tag and a data logger. A counterweight was fixed ventrally on the collar to ensure that the tag and the logger are positioned at the left dorsal side of the animal's neck. The rumination tag includes a microphone and a microprocessor. The microphone measured rumination and regurgitation sounds, and by this the rumination time in minutes was recorded. On average, the sensors were attached to the cows for 10.4 ± 2.0 d before the expected calving (ranging between 8.2 and 13.1 d). Data were stored in twelve 2-h blocks in the memory of the logger and were transferred via infrared communication and downloaded by antennas positioned above the water-trough in the barn and over the entrance of the milking parlors. At the end of the experiment, data were loaded to the HT2 Batch Tool program (SCR Engineers Ltd.), which was provided for the study by SCR Engineers Ltd. The raw data set was used to evaluate the length of single rumination periods and breaks between rumination periods. Thereby, start and end of rumination periods were labeled with a time resolution of 1 min. Rumination time was calculated and summarized at 4-h intervals.

Reticuloruminal pH and Temperature

For monitoring reticuloruminal pH and temperature, an indwelling and wireless data-transmitting system (SmaXtec Animal Care GmbH, Graz, Austria) was used. Recordings lasted from 3 d before calving until 7 DIM. After previous calibration of the pH probes, using pH 4 and 7 buffer solutions, the indwelling system (bolus; measuring 132 × 35 mm) was administered orally using a special bolus gun. The measurement interval and frequency for reticuloruminal pH and temperature values were 10 min and the stored data were transmitted to an external receiver using the ISM-Band 433 MHz (SmaXtec Animal Care GmbH). Data were read out once a day from each animal using a mobile reader, and at the end of the trial data were downloaded onto a personal computer. Following Humer et al. (2015), a specific cutoff point was established for reticuloruminal pH at the level of pH 5.8 and the daily time duration below pH 5.8 was calculated for each animal.

Parameters of Postpartum Subclinical Metabolic Disorders

Blood samples were taken by venipuncture from the coccygeal vein 2 and 24 h and 5 d after calving into heparinized tubes (S-Monovette, Sarstedt, Nümbrecht-Rommelsdorf, Germany). Samples were immediately centrifuged at 3,000 × *g* for 10 min at room temperature and the plasma was stored at −18°C until biochemical measurement. Plasma concentrations of fatty acids, BHB, triglycerides, total protein, urea, glucose, and aspartate aminotransferase activity were measured for the 5-d samples, whereas total Ca concentrations were measured for 2 and 24 h after calving as well.

Calving Management and Observation of Calvings

According to the farm practice, cows calved in the group pen or, if assistance was required, in a separate maternity pen. Supervision of the dams during calving, and the decision to move them into the maternity pen or to provide assistance, was done by the farm staff. Supervision was routinely ensured during the day, once per hour. Assistance was commonly provided to cows only when the farm personnel judged that a cow was enduring difficulty, such as absence of labor progress or distress of the dam. Further observation of the cows was performed once every 30 min.

Calvings occurring in the group pen were observed with 2 day/night outdoor network bullet cameras installed above the group pen (Vivotek IP8331, Vivotek Inc., Taipei, Taiwan). Individual calvings were observed with 2 portable video cameras (Legria HF M36, Canon Inc., Tokyo, Japan) after placing cows into the maternity pen. Dystocia was defined as calving difficulty resulting from prolonged spontaneous calving or prolonged or severe assisted extraction (Mee, 2004). Following Mee et al. (2011), normal calving (eutocia; **EUT**) was regarded as a combination of no assistance and slight assistance by 1 person. Such slight assistance (where assistance was brief, traction slight, and the cow may otherwise have calved unassisted) was provided in 2 cases. The incidence of dystocia was diagnosed by the first author based on the duration of the second stage of calving (initiated by rupture of the allantoic sac), judged by the absence of progression, straining without progress, and, in case of assisted births, the

force applied. Prolonged spontaneous calvings (>2 h from the appearance of hooves to delivery) and calvings with assistance by 2 or more people with considerable force (with a calving rope or by the use of mechanical extraction during delivery) were regarded as dystocic (**DYS**). Calves were removed from the dams within 1.5 h after birth. The first postpartum milking took place after calf removal, within the first 2 h after calving.

Statistical Analyses

All statistical analyses were performed in the R 3.0.2 statistical environment and language (R Development Core Team, 2013). As the pattern of reticuloruminal temperature is significantly influenced by water intake (Gasteiner et al., 2012), following Costa et al. (2016), only reticuloruminal temperature values higher than 37.7°C were used. The average of 24 ten-minute recordings was used for determining reticuloruminal pH for each 4-h period.

Data were tested for constant variance (Levene's test) and the Shapiro–Wilk test was used for testing normal distribution. The ANOVA was followed for the evaluation of changes in rumination time and reticuloruminal pH and temperature for EUT and DYS cows separately. Statistical significances were calculated for each variable between all time points of measurement (means ± SEM). For this purpose, Tukey's post-hoc test was used ($P < 0.05$).

For the comparison of rumination time and reticuloruminal characteristics between EUT and DYS dams, rumination time and reticuloruminal pH and temperature were calculated as area under the curve (**AUC**), which reduced the number of statistical comparisons between groups, as the numbers of repeated measurements were high (20 measurement points for the prepartum period and 41 for the postpartum period). Time to return to baseline (the time interval required to return to baseline from the delivery of the calf) was also calculated for each parameter with a 5% threshold value from baseline. The AUC and times to return to baselines were calculated for each individual, and the averaged values were used for comparisons across groups. All parameters were calculated for prepartum (between 72 h before calving and birth) and postpartum periods (between birth and 168 h after calving). To determine AUC, a trapezoid method was used (Lay et al., 1996) as follows:

$$\mathrm{AUC} = \Sigma[(\mathrm{R_n} + \mathrm{R_{n+1}})/2 \times \mathrm{h} - \mathrm{baseline}],$$

where R is a value of a rumen parameter at a given time point, n is the number of the time points, h is the time in hours between the 2 R values, and baseline is the mean value of the parameter calculated for the first 4 measurement points (−72, −68, −64, and −60 h). Postpartum AUC was determined for the 168-h postpartum period. After verifying normal distribution (Shapiro–Wilk test) and the equality of error variances (Levene's test) of data, baseline values, AUC, time to return to baseline, and daily time duration of reticuloruminal pH below 5.8 during the first 7 DIM, as well as plasma concentrations of the various metabolic parameters, were compared between groups with the Welch's 2-sample t-test ($P < 0.05$).

RESULTS

Ten calvings events were classified as EUT (female calves = 4, male calves = 6), and 8 as DYS (female calves = 4, male calves = 4). Four of the 9 multiparous cows had dystocia, whereas 5 of the 9 heifers had difficulties at calving. In 2 cases difficulty resulted from prolonged spontaneous calving, and in 6 cases difficulty resulted from assisted extraction. During the study period, Caesarean section or fetotomy was not performed. Plasma concentrations of metabolic blood parameters were in the physiological range in both EUT and DYS cows, and did not differ between groups 5 d after calving (Table 1). Total Ca concentrations were similar between EUT and DYS groups 2 h (2.01 ± 0.07 and 2.00 ± 0.10, respectively; $P = 0.92$) and 24 h after calving (1.99 ± 0.08 and 1.99 ± 0.09, respectively; $P = 1.00$).

Changes in rumination time and reticuloruminal temperature and pH are shown in Figures 1 to 3 for cows with normal and dystocic calvings. Rumination time decreased from baseline 28 h before calving both for EUT and DYS cows ($P = 0.023$ and $P = 0.017$, respectively). After 20 h before calving, it decreased to 32.4 ± 2.3 and 13.2 ± 2.0 min/4 h between 8 and 4 h before delivery in EUT and DYS cows, respectively (Figure 1), then decreased below 10 and 5 min during the last 4 h before calving ($P = 0.003$ and $P = 0.008$, respectively). A rapid increase over the first 12 h after calving was observed for rumination time for both groups. Until 12 h after delivery, rumination time reached 42.6 ± 2.7 and 51.0 ± 3.1 min/4 h in DYS and EUT dams, respectively. Subsequently, rumination time increased progressively in EUT cows to reach its baseline level within 40 h after calving; however, in DYS cows, this rise was slower, with a drop from 60.1 ± 3.7 to 40.5 ± 2.6 min/4 h around the time of introducing dams into the fresh lactation group (Figure 1). We found no difference between groups in basal rumination activity and in AUC rumination time during the prepartum period (Table 2). The AUC rumination

Table 1. Plasma concentrations (means ± SD) of metabolic blood parameters 5 d after calving in eutocic (EUT) and dystocic (DYS) cows

		Calving group[1]		
Blood parameter	Unit	EUT	DYS	*P*-value[2]
Fatty acids	mmol/L	0.5 ± 0.1	0.4 ± 0.1	NS
BHB	mmol/L	1.1 ± 0.1	1.0 ± 0.1	NS
Aspartate aminotransferase	IU/L	85 ± 7	88 ± 8	NS
Total protein	g/L	62.4 ± 8.4	60.3 ± 7.4	NS
Glucose	mmol/L	3.2 ± 0.3	3.1 ± 0.4	NS
Triglycerides	mmol/L	0.12 ± 0.03	0.11 ± 0.02	NS
Urea	mmol/L	5.1 ± 1.2	5.0 ± 1.3	NS
Ca	mmol/L	2.1 ± 0.1	2.2 ± 0.1	NS

[1]EUT = eutocic calving; a combination of no assistance and slight assistance by one person. DYS = dystocic calving; prolonged spontaneous calving (>2 h from appearance of hooves to delivery) or calving with assistance by 2 or more persons with considerable force.

[2]Statistical significances are based on the Welch's 2-sample *t*-test.

time calculated for the postpartum period was greater in DYS cows than in EUT dams, and rumination time required more time to return to baseline in DYS cows than in EUT ones (Table 2).

Reticuloruminal pH showed a similar pattern between groups for the entire recording period (Figure 2), and no difference was found in AUC reticuloruminal pH between EUT and DYS cows before calving (Table 3). Reticuloruminal pH decreased from baseline 56 h before calving in EUT and DYS cows ($P = 0.012$ and $P = 0.016$, respectively), then varied between 6.07 and 6.35 until calving, and subsequently decreased rapidly within the first 16 h after calving. For the remainder of the observation period, reticuloruminal pH had higher levels in DYS cows than in EUT dams, with a drop in DYS cows around the time of introducing the animals to the fresh lactation group ($P < 0.01$ from baseline).

Time duration of reticuloruminal pH below 5.8 was higher ($P = 0.032$) in EUT cows compared with DYS dams during the first 7 DIM and areas under the pH curves indicated lower overall postpartum reticuloruminal pH levels in EUT dams than in DYS cows (Table 3). Although reticuloruminal pH did not decrease below the critical 5.5 level, it returned to baseline neither in EUT nor in DYS cows within the 168-h postpartum period.

In DYS cows, reticuloruminal temperature decreased from baseline 32 h before calving with 0.23 ± 0.02°C ($P = 0.012$), whereas in EUT animals a more pronounced drop was observed (0.48 ± 0.05°C, $P < 0.01$), but only 20 h before calving (Figure 2). Reticuloruminal temperature reached the lowest peak in EUT and DYS cows 16 h before calving (38.9 ± 0.08 and 39.17 ± 0.05°C, respectively), then increased gradually until the time of delivery in both groups. During the first 4 h after calving, reticuloruminal temperature decreased from 39.68 ± 0.09 to 38.96 ± 0.10°C and from 39.80 ± 0.06 to 38.81 ± 0.08°C in EUT and DYS cows, respectively ($P < 0.01$ for both groups). It peaked at 24 h after calving in both groups, then decreased to baseline levels with minor alterations for both groups. We observed no difference in basal reticuloruminal temperatures between the groups. Although AUC reticuloruminal temperature calculated for the prepartum period was greater in EUT cows than in DYS cows, no differences were observed between the groups for postpartum reticuloruminal temperatures in terms of AUC and time to return to baseline (Table 3).

DISCUSSION

Monitoring of cows before calving allows the appropriate timing of obstetric assistance, which can reduce the losses caused by dystocia (Kovács et al., 2016). It is well known that the last 24 h before calving are characterized by increases in lying frequency, walking frequency, and tail raising frequency in dairy cows (Miedema et al., 2011b); however, the great interindividual variability in these behaviors might prevent the precise identification of the time of imminent calving. Previous studies have shown that behavioral changes associated with parity of the cow could potentially be confounded by difficulty at calving (Wehrend et al., 2006; Mainau Brunsó, 2011). This was taken into account in the present study, as 9 heifers and 9 multiparous cows were included and the distribution of cows and heifers was similar between the EUT and DYS groups.

Rumination behavior is considered to be influenced by 4 main groups of factors: feeding (Kononoff and Heinrichs, 2003), animal (Richter, 2010), disease (Pedersen, 2010) and environment, such as regrouping of the animals or moving animals into another group based on milk production (Schirmann et al., 2011). All these factors are extensively studied in the literature. The present study uncovered differences in rumination time

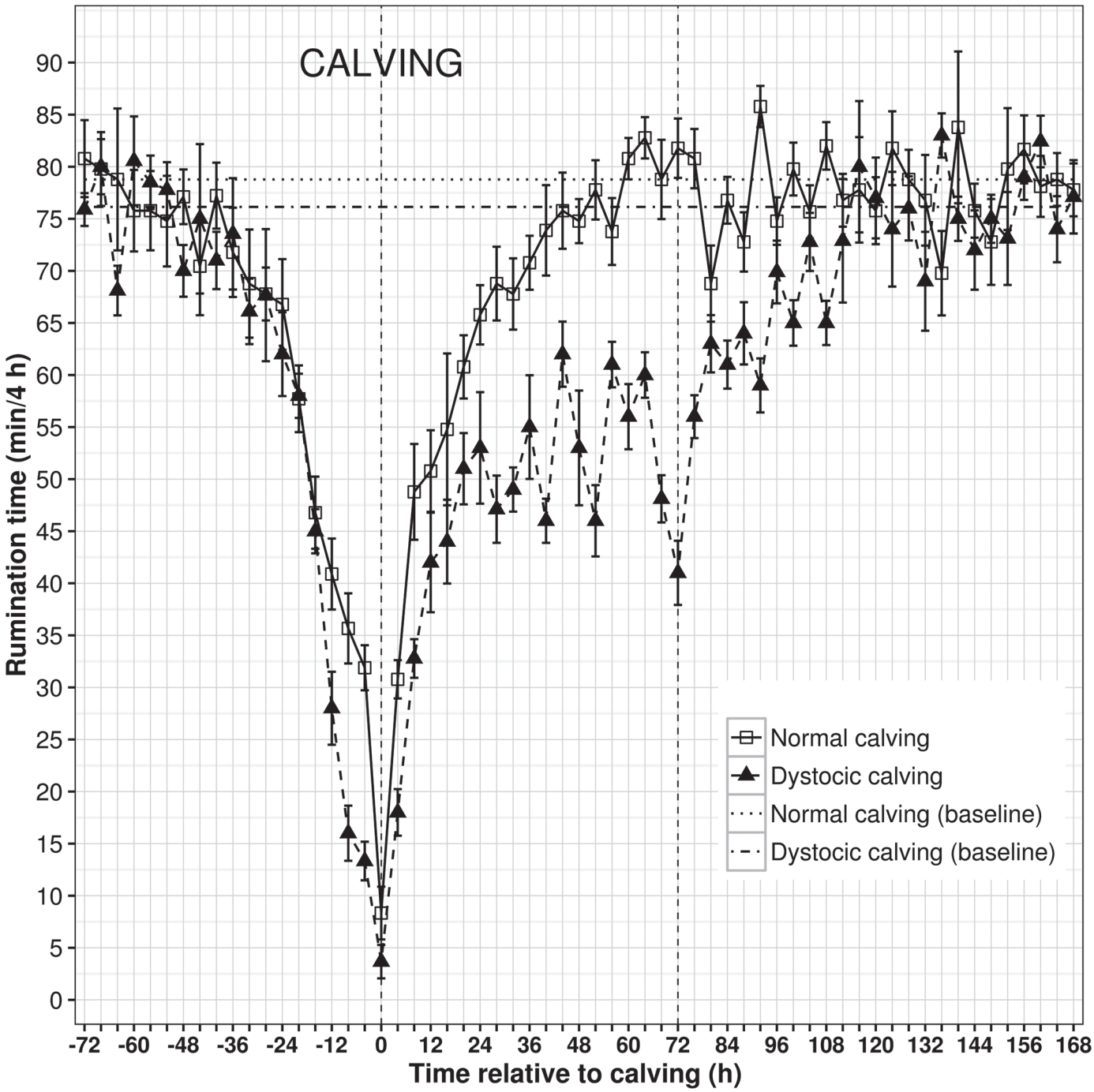

Figure 1. Rumination time (min/4 h) in dairy cows with normal (n = 10) and dystocic calvings (n = 8) around parturition. Data are given as means ± SEM; time 0 represents the last 4 h before calving, and the dashed vertical line at 72 h after calving indicates the time of introducing cows to the fresh lactation group.

between cows with normal and difficult calvings. In particular, lower rumination activity was observed for DYS cows than for dams with normal calvings within 8 h before calving, and rumination time remained depressed for a longer period of time in DYS cows than in EUT dams.

Between 24 and 12 h before calving rumination time decreased in both groups. This is the time interval when an impaired cardiac autonomic function was observed in dairy cows (Kovács et al., 2015) with unassisted calvings. In Kovács et al. (2015), a decline in vagal tone reflected acute visceral pain, which was

possibly higher in the present work in cases of difficult deliveries, as from 16 h antepartum the decline in rumination time was more rapid in DYS cows than in EUT animals (Figure 1). The clear differences between EUT and DYS cows between 4 and 8 h antepartum, with around a 3-fold lower rumination time for DYS cows compared with EUT ones, may also suggest a higher levels of stress in DYS cows. An earlier study found that rumination activity is influenced by acute stress (Herskin et al., 2004). The fact that overall rumination times, calculated as AUC, did not differ during the prepartum period between groups resulted from the

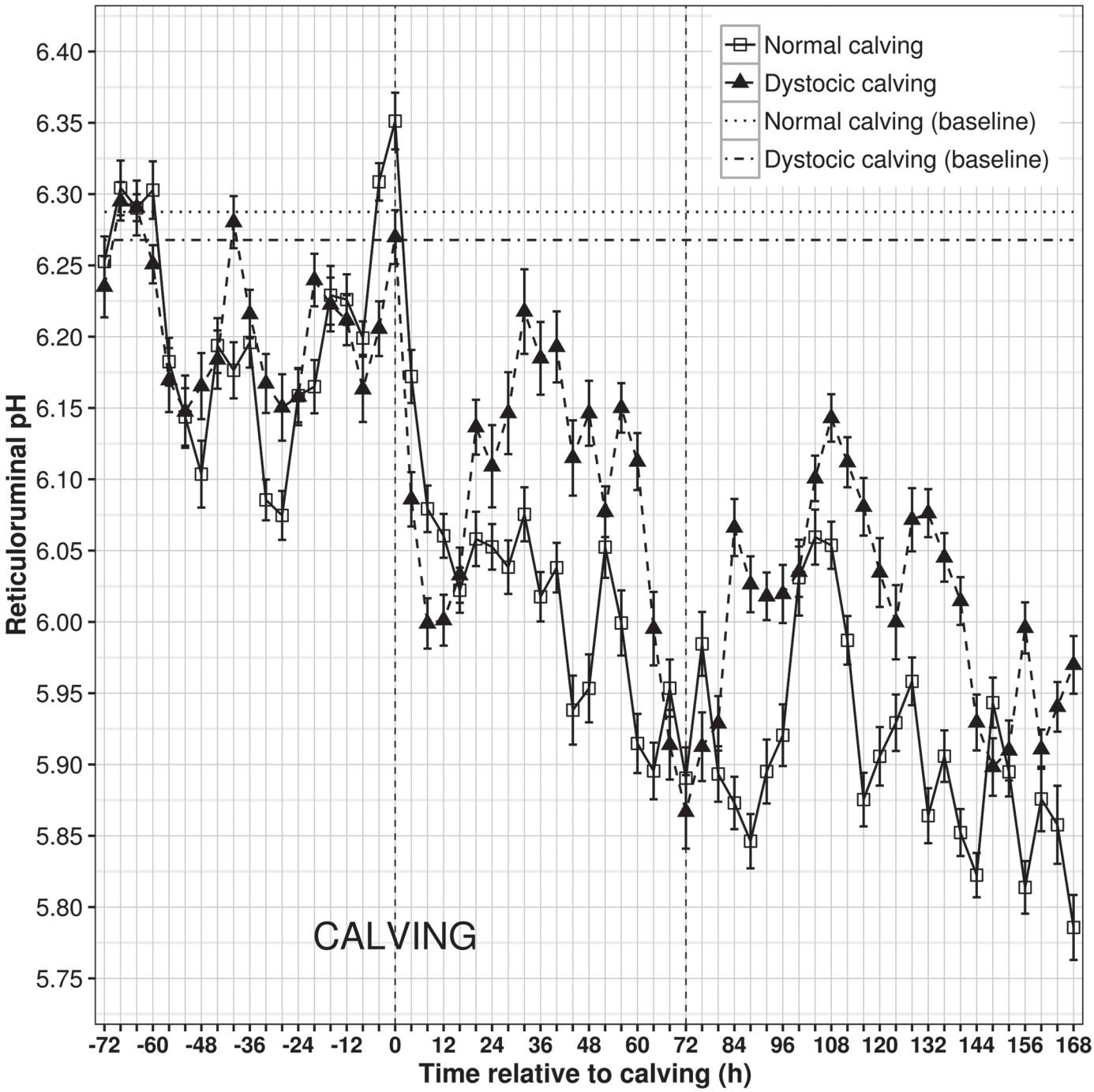

Figure 2. Reticuloruminal pH in dairy cows with normal (n = 10) and dystocic calvings (n = 8) around parturition. Data are given as means ± SEM; time 0 represents the last 4 h before calving, and the dashed vertical line at 72 h after calving indicates the time of introducing cows to the fresh lactation group.

relatively long-term observation period before calving and the similar pattern of rumination activity in EUT and DYS cows until 16 h before delivery. Pahl et al. (2014) also found a significant decrease in rumination time, but only in the last 6 h before calving; however, those authors used only animals with normal or slightly assisted calvings.

The postpartum resumption of rumination activity was slower in DYS cows. The time spent with rumination within the first 4 h after calving was almost

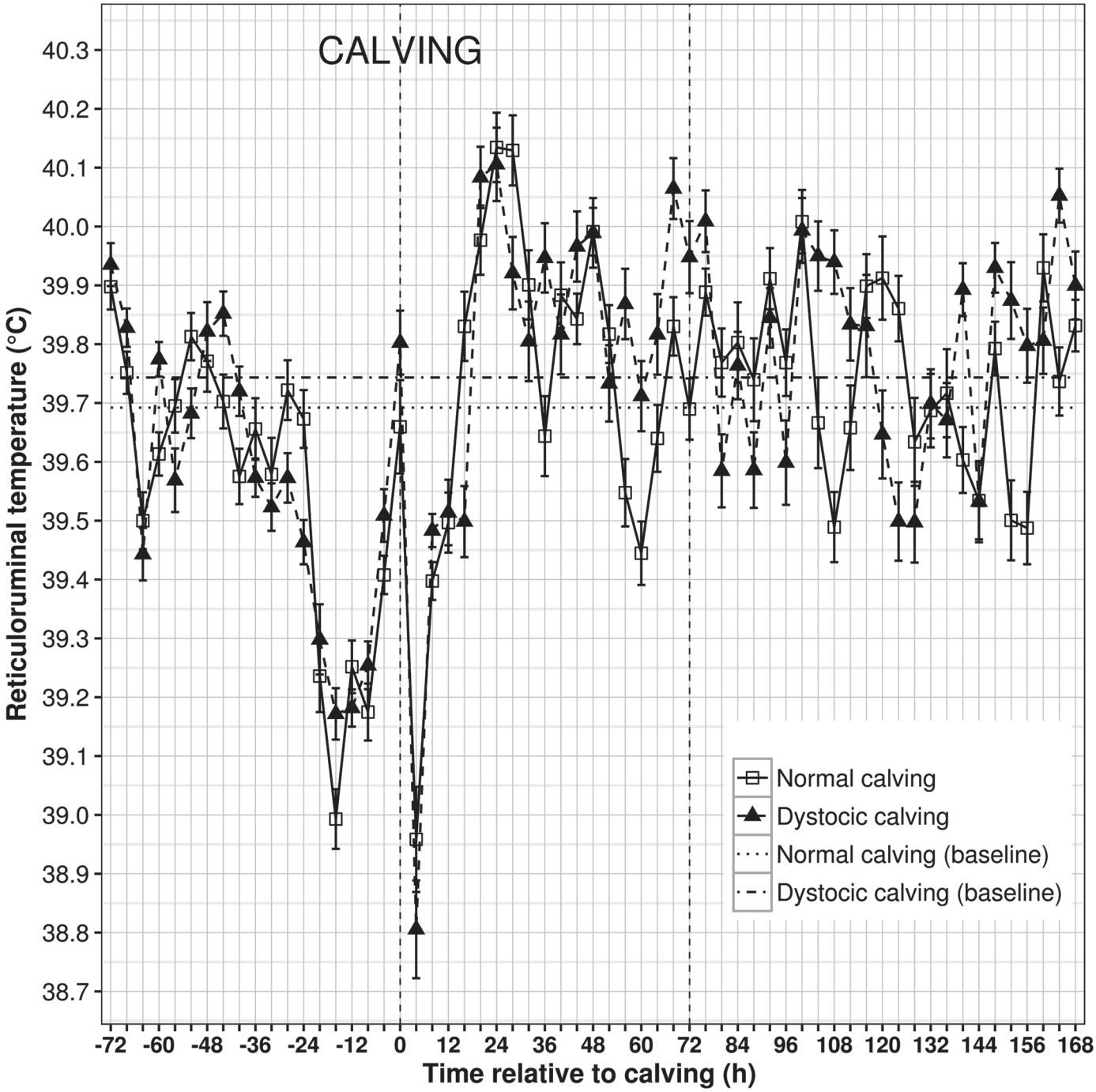

Figure 3. Reticuloruminal temperature (°C) in dairy cows with normal (n = 10) and dystocic calvings (n = 8) around parturition. Data are given in means ± SEM; time 0 represents the last 4 h before calving, and the dashed vertical line at 72 h after calving indicates the time of introducing cows to the fresh lactation group.

Table 2. Rumination time calculated as area under the curve (means ± SD) before and after calving in eutocic (EUT) and dystocic (DYS) cows

Rumination time parameter[1]	Unit	Calving group[2]		*P*-value[3]
		EUT	DYS	
Baseline	min/4 h	78.3 ± 2.8	76.1 ± 2.3	NS
AUC_{PRE}	min	−4,378.5 ± 421.4	−4,756.2 ± 345.8	NS
AUC_{POST}	min	−9,923.6 ± 764.1	−12,420.3 ± 1,043.7	0.012
Time to return to baseline	h	39.8 ± 7.6	97.2 ± 12.4	0.002

[1]AUC_{PRE} = area under the curve calculated for the last 72 h before calving; Baseline = between 72 and 60 h before calving; AUC_{POST} = area under the curve calculated for the first 168 h after calving.

[2]EUT = eutocic calving; a combination of no assistance and slight assistance by one person. DYS = dystocic calving; prolonged spontaneous calving (>2 h from appearance of hooves to delivery) or calving with assistance by 2 or more persons with considerable force.

[3]Statistical significances are based on the Welch's 2-sample *t*-test.

2-fold higher in EUT cows compared with cows with difficulties at calving. The low rumination activity continued several hours beyond calf removal in DYS cows; therefore, the presence of the calf, and thus the parent-offspring interaction, might not have had a considerable effect on the short-term resumption of rumination.

Resumption of rumination activity after calving is directly linked to the start of feed intake. Schirmann et al. (2013) reported recovery at 6 h after calving, which might explain the recovery of rumination time from 8 h postpartum found in the present study. The postpartum rumination time observed for EUT dams in our study was within the range reported in the literature (Yang and Beauchemin, 2006; Calamari et al., 2014); however, dystocia had a pronounced effect on postpartum rumination activity in the long term as well. Rumination time required 2 d to return to its physiological level in EUT cows, whereas the significant reduction of rumination activity persisted until 4 d postpartum in DYS cows, as indicated by time to return to baseline. A previous work reported similar results in healthy cows, but without reporting the course of calving; that is, rumination time reached a stable level at 5 d after calving (Bar, 2011). A delay in resuming rumination is considered an alert signal and might be related to disturbed feed intake or health disorders. However, in the present study, no evidence was found for subclinical metabolic disorders during the postpartum period in EUT or in DYS cows. The BHB, fatty acid, and glucose concentrations did not match the clinical signs of subclinical ketosis (González et al., 2011) and high lipomobilization (fatty acids >0.7 mmol/L) was detected only in 1 cow in the DYS group. Hepatic lipidosis and compromised hepatic function was not observed as shown by plasma aspartate aminotransferase activity and glucose, triglycerides, and urea concentrations being within the reference ranges. According to Hansen et al. (2003), rumination activity is influenced by subclinical hypocalcemia; however, plasma Ca concentrations were similar between groups either 2 and 24 h and 5 d after calving, and 4 and 5 animals showed slightly lower Ca levels than 2 mmol/L at 2 and 24 h after calving, respectively. As the effect of subclinical metabolic disorders does not seem to explain the difference in postpartum rumination time between EUT and DYS cows, our findings rather reflect the long-term effects of pain and discomfort associated with prolonged or severe extraction in dams experienced difficulties at calving.

In contrast to what had been expected, DYS cows had higher postpartum reticuloruminal pH values than EUT dams, as shown by AUC analysis and daily time duration with pH below 5.8. As these differences were slight, based on the present data, no serious effects of dystocia on postpartum reticuloruminal pH could be assumed. The slightly higher pH values observed for DYS cows might be attributed to lower DMI from the postpartum diet with a high concentrate ratio. In healthy cows, a rapid recovery of feed intake was observed after calving (Mainau and Manteca, 2011; Sato et al., 2012), which was supposedly impaired in cows with difficulties at calving in the present work. It is a shortcoming of our study that DMI as the main trigger of both rumination time and reticuloruminal pH was not recorded.

A decreasing tendency in postpartum reticuloruminal pH is thought to be normal (Gasteiner and Guggenberger, 2013), and it was clearly seen in the present study (Figure 2). Reticuloruminal pH values below 5.5 are considered abnormal and suggestive of either severe SARA (Garrett et al., 1999) or, in combination with clinical signs, peracute or acute acidosis (Blood and Radostits, 1989). In a recent study, the daily time duration below reticuloruminal pH 5.8 was 15 and 753 min in SARA-tolerant and -susceptible cows, respectively, between 2 and 8 DIM (Humer et al., 2015). In the present work duration below pH5.8 did not reach 10 min/d during the first 7 DIM in EUT or DYS dams, and

Table 3. Reticuloruminal pH and temperature characteristics (means ± SD) before and after calving in eutocic (EUT) and dystocic (DYS) cows

Item[1]	Unit	Calving group[2]		*P*-value[3]
		EUT	DYS	
Reticuloruminal pH parameters				
Baseline		6.29 ± 0.10	6.27 ± 0.08	NS
AUC_{PRE}	h	−11,222 ± 546	−11,015 ± 411	NS
AUC_{POST}	h	−25,314 ± 737	−21,877 ± 2,350	0.046
Time to return to baseline	h	NA	NA	NA
Time duration below pH 5.8 during the first 7 DIM	min/d	9.4 ± 7.5	4.3 ± 3.1	0.032
Reticuloruminal temperature parameters				
Baseline	°C	39.7 ± 0.4	39.7 ± 0.6	NS
AUC_{PRE}	°C × h	−67,757 ± 1,223	−65,018 ± 1,145	0.042
AUC_{POST}	°C × h	150,522 ± 35,512	141,529 ± 18,031	NS
Time to return to baseline	h	35.4 ± 3.4	37.8 ± 4.2	NS

[1]AUC_{PRE} = area under the curve calculated for the last 72 h before calving; Baseline = between 72 h and 60 h before calving; AUC_{POST} = area under the curve calculated for the first 168 h after calving.

[2]EUT = eutocic calving; a combination of no assistance and slight assistance by one person. DYS = dystocic calving; prolonged spontaneous calving (>2 h from appearance of hooves to delivery) or calving with assistance by 2 or more persons with considerable force. NA = not available.

[3]Statistical significances are based on the Welch's 2-sample *t*-test. NA = not available.

reticuloruminal pH exceeded the critical 5.5 level in all studied animals throughout the study period, thus providing no evidence for postpartum rumen acidosis.

Besides a slow decline, reticuloruminal pH showed characteristic rises and falls during the postpartum period in both EUT and DYS cows. Diurnal variations in reticuloruminal pH were previously explained by a repeated diurnal feed intake pattern (Robinson and Garrett, 1999); however, our results can be only partly explained by this phenomenon, as animals did not calve at the same time of day. Therefore, all measurement points were time shifted. Periodic changes in reticuloruminal pH mirror the adaptation of the rumen to the postpartum diet.

Although there is evidence that dairy cows exhibit a distinct decrease in vaginal and rectal temperatures commencing approximately 48 h before calving (Birgel et al., 1994; Dufty, 1971; Aoki et al., 2005), the detection of this decrease does not determine the onset of calving precisely (Burfeind et al., 2011). In a more recent work, Costa et al. (2016) identified an average drop in reticuloruminal temperature of ≥0.2°C within 24 h before calving as the best predictor of the imminent calving based on sensitivity, specificity, and diagnostic odds ratios. We found sudden drops in reticuloruminal temperature 32 and 20 h before calving with 0.23 and 0.48°C in DYS and EUT cows, respectively. Although our data needs further confirmation, as this drop occurred 12 h earlier in DYS cows compared with EUT dams, we suggest that reticuloruminal temperature should be considered a possible predictor of dystocic calving events not only in future studies but in herd management systems as well.

Our study has shown the effects of dystocia on rumination activity around calving. Although rumination time varies between and within herds (Moallem et al., 2010; Calamari et al., 2011), continuous monitoring of changes in rumination time at cow level seems to be useful in the early detection of cows with a higher risk of calving difficulties. Impaired rumination activity of DYS cows within the first 4 d after calving highlights the importance of paying particular attention to the feeding management of cows that have had a difficult calving. Prepartum drops in reticuloruminal temperature underscore the promising value of this parameter in the early detection of dystocia. As strong interanimal variations in reticuloruminal pH responses to parturition exist (Humer et al., 2015), investigations involving a larger number of animals are required to study the effects of difficult calving on reticuloruminal pH. For a better understanding of the effect of dystocia on rumination time and reticuloruminal pH and temperature, exploration of physiological mechanisms associated with peripartal rumination patterns is still necessary. Further studies should focus on the various effects of obstetrical conditions on rumination time and reticuloruminal characteristics by considering the severity of dystocia as well.

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