Periparturial changes in reticuloruminal pH and temperature in dairy cows differing in the susceptibility to subacute rumen acidosis

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ABSTRACT

The present study aimed to investigate changes in the reticuloruminal pH and temperature dynamics in periparturient dairy cows. Reticuloruminal pH and temperature measurements were conducted from 7 d before until 8 d after parturition using indwelling sensors. Nine Simmental and 4 Brown Swiss dairy cows were fed a close-up total mixed ration (52.5% neutral detergent fiber, 5.68 MJ of net energy for lactation per kg of dry matter) with additional 1 kg/cow per d concentrate mixture (29.5% neutral detergent fiber and 6.25 MJ of net energy for lactation per kg of dry matter), starting from 2 wk before the estimated calving date. Postpartum, all cows had free access to the same close-up diet and were gradually fed increasing amounts of a concentrate-rich total mixed ration for early-lactation cows (32.7% neutral detergent fiber, 7.22 MJ of net energy for lactation per kg of dry matter). Data showed depressed reticuloruminal pH early postpartum, but only in the group of cows defined as subacute ruminal acidosis (SARA) susceptible ($n = 8$), which had a higher duration time of pH <5.8 (753 ± 82 min/d) compared with SARA-tolerant cows ($n = 5$; 15 ± 6 min/d). Also, compared with SARA-tolerant cows (112 ± 91 min/d), the SARA-susceptible group showed longer ($1,049 \pm 75$ min/d) duration time of pH <6.0 . When compared by breed, mean reticuloruminal pH tended to be lower in Simmental (6.16 ± 0.03) than in Brown Swiss cows (6.25 ± 0.05), but no differences were observed in the duration of pH <5.8 between breeds. Simmental cows produced more milk (30.4 ± 1.2 kg/d) compared with Brown Swiss cows (27.9 ± 1.3 kg/d). Neither total dry matter intake nor milk yield were different between SARA-susceptible and SARA-tolerant groups. However, SARA-tolerant cows consumed

greater amounts of the close-up total mixed ration than their SARA-susceptible counterparts, whereas no difference was observed in the intake of the early-lactating total mixed ration between the groups. Reticuloruminal temperature was not affected by breed or SARA susceptibility. Interestingly, the mean reticuloruminal temperature and the time duration of temperature $>39.5^\circ\text{C}$ abruptly dropped from d 2 to 1 before calving by 0.35°C and 430 min/d, respectively. In conclusion, the strong inter-animal variation in reticuloruminal pH responses suggests the need for more careful monitoring and differentiated feeding management of cows during the transition period, whereby the SARA-susceptible cows may require particular attention regarding feeding management and diet composition. The abrupt decrease in reticuloruminal temperature the day before parturition may enable this noninvasive method as a management tool for prediction of parturition time.

Key words: rumen pH, cow health, parturition, temperature, ruminal acidosis

INTRODUCTION

The transition from pregnancy to lactation is stressful and critical for health and productivity of dairy cows because this period is characterized by strong metabolic, immune, and endocrine changes (Esposito et al., 2014). Feeding management during this period is crucial to ensure a smooth metabolic adaptation of the cow to changes across multiple tissues and the dramatic increasing nutrient demand after parturition (Roche et al., 2013). Accordingly, the main nutritional goal is to mitigate postparturial deficits in energy and nutrients by gradually increasing concentrate amounts while maintaining proper rumen functioning and prevention of rumen disorders, such as SARA (Rabelo et al., 2003; Zebeli et al., 2010; Roche et al., 2013). Thus, it is important to alleviate the metabolic stress postpartum because SARA may lead to suboptimal digestion and impaired health status (Plaizier et al., 2008; Zebeli and Metzler-Zebeli, 2012). Suboptimal ruminal digestion may lower the energy and nutrient supply for the host,

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thus aggravating the nutritional deficit of the transition cow further (Khiaosa-Ard and Zebeli, 2014).

Early diagnosis of SARA during the transition period is important to prevent complications at an early stage and enhance cow health. However, SARA lacks overt clinical signs and the change in milk fat content, which is routinely used in the practice to diagnose SARA, is not an accurate indicator of SARA during early lactation (Zebeli et al., 2008). The SARA is characterized by repeated episodes of the ruminal pH being depressed below pH 5.6 (Plaizier et al., 2008) or 5.8 (Zebeli et al., 2008), whereby the extended duration of suboptimal pH below SARA thresholds indicates the severity of SARA (Penner et al., 2007). Therefore, the diagnosis of SARA and evaluation of its severity can be determined by continuous monitoring of ruminal pH with higher accuracy than by single-point measurements of rumen pH (Penner et al., 2007; Klevenhusen et al., 2014). Nevertheless, a growing body of evidence suggests considerable variability in the ability of periparturient cows to cope with a shift to energy-rich diets, and hence in their susceptibility to SARA (Penner et al., 2009; Bannink et al., 2012; Mohammed et al., 2012). These differences might be related to differing feeding and ruminating behavior (Gao and Oba, 2014), morphological and physiological differences of the rumen epithelium (Bannink et al. 2012), and also to differing microbial ruminal populations (Penner et al., 2009; Mohammed et al., 2012).

Besides pH, ruminal temperature may also indirectly indicate SARA conditions in cows (AlZahal et al., 2008). In fact, continuous ruminal pH systems enable simultaneous monitoring of ruminal pH and temperature using the same indwelling sensor (Humer et al., 2015). On the other hand, because rumen temperature is correlated with body temperature (Bewley et al., 2008), and the latter is related to physiological functions such as parturition in dairy cows (Cooper-Prado et al., 2011), the temperature of the reticulorumen might also change during the periparturient period, thus being an indicator of calving time. Because 70% of the calf deaths occurring during the first 24 h after calving are caused by dystocia (Patterson et al., 1987), the prediction of calving time is of great importance to enable obstetrical assistance and increase the survival rate of calves (Bellows et al., 1987).

Thus, monitoring the rumen temperature around calving may help predicting physiological events in field conditions, whereas simultaneous monitoring of the rumen pH may help diagnosing SARA at an early phase. Because reports regarding the periparturient reticulorumen pH and temperature changes are scarce, this study evaluated reticulorumen pH and temperature

dynamics and susceptibility of SARA in periparturient dairy cows switched gradually from a forage-rich close-up diet to a grain-rich high-lactation diet. Additionally, potential differences between breeds to cope with SARA around parturition were investigated.

MATERIALS AND METHODS

Animals, Housing, and Feeding

All procedures involving animal handling and treatment were approved by the institutional ethics committee of Vetmeduni Vienna and the national authority according to § 26 of the Law for Animal Experiments, Tierversuchsgesetz 2012, BGBl. I Nr. 114/2012, (permission of animal experiment: BMFWF-68.205/0064-WF/II/3b/2014). Nine Simmental (BW: 781 ± 34 kg) and 4 Brown Swiss cows (BW: 643 ± 22 kg), starting from 2 wk before the estimated calving date, were used in the study. The Simmental cows included 1 primiparous and 8 multiparous animals, whereas the Brown Swiss cows included 2 primiparous and 2 multiparous cows. All cows calved between June and July 2014 and were housed at the dairy research station Kremesberg of the Vetmeduni Vienna in individual pregnancy pens with straw as bedding material and a space allowance of 8 m² for each cow. During the periparturient period, all cows had ad libitum access to a forage-rich close-up TMR (Table 1), offered to the cows twice daily at 0800 and 1630 h in their pens. In addition to the close-up TMR, starting from 2 wk before the estimated day of parturition until the parturition day, each cow received 1 kg/d of a concentrate mixture for pregnant cows (Table 1). Fresh water was available ad libitum within each pen. Routine veterinary examination was provided to the cows daily. Within 8 h after calving, all cows received an energy, electrolyte, and micronutrient supply (Rindavital, Schaumann, Pinneberg, Germany, Table 1). After calving, the cows were housed in a free stall equipped with individual feeders with electronic weighing scales and computer-regulated access gates (Insentec B.V., Marknesse, the Netherlands) to measure and control the individual feed intake of the cows. Postpartum, the cows had ad libitum access to the same close-up TMR and additionally were provided access to increasing amounts of a TMR for early lactation cows (Table 1), in separate feeders. Daily allowances of TMR for early-lactation cows were set at 5 kg of DM per cow on the first day after parturition and increased daily by 1.5 kg of DM/cow per d until d 6 and by 1 kg DM/cow per d per d from d 6 to d 8 postcalving, being offered twice daily at 0800 and 1630 h. Cows were milked at 0600 and 1530 h in a tandem milking parlor. The DMI

of the close-up and early-lactation TMR as well as the milk yield of each cow were recorded daily from 1 to d 8 postpartum.

Reticuloruminal pH and Temperature

To monitor rumen pH continuously, all cows received an indwelled wireless pH-transmitting unit (SmaXtec Animal Care Sales GmbH, Graz, Austria), which has been validated recently in a dairy cattle experiment with rumen-cannulated cows (Klevenhusen et al., 2014). These units (3.5 cm i.d., 12 cm long, and weighing 210 g) were manually inserted into the reticulorumen via the esophagus on d 8 before the expected calving date. Prior to this, the units were calibrated by a 1-point calibration using a buffer of pH 7.0 following the company's instruction protocol. The units measured pH and temperature every 10 min and transmitted the data in real time to a basis station using the ISM band (433 MHz). Antennas installed in the barn and milking parlor picked up the sensor signals. Both data of pH and temperature were collected using an analog-to-digital converter and stored in an external memory chip. The measurements were taken continuously from each cow

until d 8 postpartum. Data of pH from d 7 before to d 8 after calving were analyzed as daily mean pH and time (min/d) below specific cut-off points (5.5, 5.8, and 6.0). Because wireless sensors are located in the ventral reticulorumen (Gasteiner et al., 2009) and little differences were observed between pH measured by wireless units and in the ventral rumen sac (Klevenhusen et al., 2014), the term reticuloruminal pH is used here. Data of temperature were analyzed as daily mean temperature and duration during which the temperature was above a threshold of 39.5°C. This temperature threshold was selected as presenting body temperatures that are moderately above normal (Wahrmund et al., 2012), as reticuloruminal temperatures are generally about 0.5°C higher than core body temperatures (Prendiville et al., 2002).

Classification of SARA Susceptibility and Health Status, Diseases, and Treatments of the Cows

For the diagnosis of SARA, we used the time duration of reticuloruminal pH <5.8 of longer than 330 min/d (Zebeli et al., 2008). Animals were classified as SARA susceptible ($n = 8$, 5 Simmental and 3 Brown Swiss

Table 1. Ingredients and nutrient composition of diets

Item	Close-up TMR ¹	Early-lactation TMR
Ingredient (% of DM)		
Meadow hay	23.7	10.0
Grass silage	33.3	10.0
Corn silage	14.8	33.0
Concentrate mixture ²	—	47.0
Dried distillers grains with solubles	5.9	—
Chopped wheat straw	22.3	—
Nutrient composition (% of DM unless otherwise stated)		
DM (% of fresh feed)	56.4	46.1
Ash	5.6	6.9
CP	12.0	19.1
NDF	52.5	32.7
ADF	31.6	20.3
Ether extract	3.3	2.8
NFC ³	26.6	38.5
NE _L (MJ/kg of DM)	5.68	7.22

¹Besides having ad libitum access to the close-up TMR, each cow received 1 kg/d of a concentrate mixture (15.9% CP, 29.5% NDF, and 6.25 MJ of NE_L per kg of DM) for pregnant cows (Rimin Vital, Garant, Pöchlarn, Austria), starting from 2 wk before the estimated parturition until the calving day. Rimin Vital contained 50% wheat bran, 29% wheat, 4% molasses, 2.5% barley, 1.8% sunflower meal, 1.5% cocoa shells, 1.5% rapeseed meal, and 9.7% mineral vitamin premix (containing 0.4% Ca, 0.8% P, 1.4% Mg, 1.1% Na, 400 mg/kg of Mn, 750 mg/kg of Zn, 170 mg/kg of Cu, 100,000 IU/kg of vitamin A, 20,000 IU/kg of vitamin D₃, 1,000 mg/kg of vitamin E). Within 8 h after calving, all cows received 500 g of Rindavital (Schaumann, Pinneberg, Germany) dissolved in 20 L of water as rapid energy, electrolyte, and micronutrient supply early postpartum. This supplement contained 72% glucose, 12% salt, 10% monocalcium phosphate, and 2% sodium hydrogen carbonate, 4,000 mg of vitamin E, 50 mg of Co, 10 mg of Se, and 19.0×10^9 cfu *Saccharomyces cerevisiae* per kg of DM.

²Contained 55% barley, 25% soybean meal, 9% rapeseed meal, 4% wheat bran, 3% dried beet pulp, 2% mineral vitamin premix (contained 16% Ca, 4% P, 7% Mg, 10% Na, 3,325 mg/kg of Mn, 5,000 mg/kg of Zn, 1,000 mg/kg of Cu, 100,000 IU/kg of vitamin A, 100,000 IU/kg of vitamin D₃, 4,000 mg/kg of vitamin E), 0.45% limestone, 0.25% salt, 0.8% monocalcium phosphate, and 0.5% urea.

³Nonfiber carbohydrates = $100 - (\% \text{ NDF} + \% \text{ CP} + \% \text{ ether extract} + \% \text{ ash})$.

cows, BW: 748 ± 120 kg) when the duration of reticuloruminal pH < 5.8 exceeded 330 min/d at least during 1 of the first 8 d after parturition. If this criterion was not met, cows were considered as SARA tolerant ($n = 5$, 4 Simmental, 1 Brown Swiss, BW: 709 ± 77 kg). The SARA-susceptible group included 2 primiparous and 6 multiparous cows (average lactation number: 3.63 ± 1.92), whereas the SARA-tolerant group included 1 primiparous and 4 multiparous cows (average lactation number: 3.50 ± 2.65). One cow of the SARA-susceptible group (Brown Swiss, multiparous) was diagnosed with metritis on d 1 postpartum. The cow was treated with an antibiotic (Excenell RTU EZ, Zoetis GmbH, Vienna, Austria) as well as an antiphlogistic agent (Rifen, Richter Pharma AG, Wels, Austria), administered daily at 24-h interval for a total of 3 consecutive days. Furthermore, one cow of the SARA-tolerant group (Simmental, multiparous) was diagnosed with subclinical hypocalcemia on d 5 postpartum and received 400 mL of calcium borogluconate (Calciumborogluconat-Infusionslösung, Serumwerk Bernburg, Germany) intravenously. Both cows showed satisfactory response to the treatments.

Feed Sampling and Chemical Analyses

Samples of the TMR were collected weekly. They were mixed and aliquots were used for analyses of nutrient composition. Dry matter was determined after oven-drying for 72 h at 55°C . The ground samples (1-mm screen) were analyzed for N using the Kjeldahl method, ether extract and ash were measured according to the official methods (Naumann and Bassler, 2012). The NDF and ADF were determined using the methods described by Van Soest et al. (1991), with heat-stable α -amylase used in the NDF procedure.

Statistical Analyses

Data were analyzed for normality using the Shapiro-Wilk test. The ANOVA was performed using the MIXED procedure of SAS (version 9.2, SAS Institute Inc., Cary, NC). For each response variable tested, the model included the fixed effects of day relative to calving, breed, SARA susceptibility, as well as the resulting 2-way interaction between day relative to calving and SARA susceptibility. The model initially included the interaction of breed and day, but this was not significant and was therefore removed. The parity was considered as a random effect in the model. The data gained from the same cow but at different days relative to calving were considered as repeated measures in the model with a first-order autoregressive heterogeneous variance-covariance matrix. Degrees of freedom were estimated with the method of Kenward-Roger. The

PDIFF option was used in each of the comparisons. Associations among DMI, nutrient intake, pH, and temperature measurements were studied by performing a Pearson correlation (PROC CORR of SAS). The significance level was set at $P \leq 0.05$, and a trend was considered up to the $0.05 < P \leq 0.10$ level.

RESULTS

Peripartal Reticuloruminal pH Changes

Differences in mean reticuloruminal pH between the 2 breeds from d 7 prepartum to d 8 postpartum are shown in Figure 1a. A tendency for lower ($P = 0.08$) pH values was recorded in Simmental cows (6.16 ± 0.03) compared with Brown Swiss cows (6.25 ± 0.05). An overall decrease of reticuloruminal pH was observed starting from d 3 after calving. Differentiation between SARA-susceptible and SARA-tolerant cows revealed that a decrease in pH after parturition occurred only in the first group (Figure 1b). In the cows of the SARA-susceptible group, mean pH showed lower values compared with SARA-tolerant cows from d 4 to d 8 after parturition ($P < 0.05$).

Time duration of reticuloruminal pH below 6.0, 5.8, and 5.5 did not differ between breeds (data not shown). However, similar to mean reticuloruminal pH, the time duration of pH < 6.0 differed between SARA-susceptible and SARA-tolerant cows ($P < 0.01$, Figure 2a). Furthermore, an interaction between the day relative to calving and SARA susceptibility was observed ($P < 0.01$). Although no differences between the 2 SARA-susceptibility groups were found until d 2 after calving, a marked difference occurred thereafter. Thus, from d 2 to 8 after parturition, the reticuloruminal pH of SARA-susceptible cows dropped below 6.0 for $1,049 \pm 75$ min/d compared with 112 ± 91 min/d in SARA-tolerant cows ($P < 0.01$). In addition, the duration of pH < 5.8 differed from d 4 postpartum to d 8 postpartum between SARA-susceptible and SARA-tolerant cows (Figure 2b, $P < 0.01$), whereby SARA-susceptible cows showed an average duration of 753 ± 82 min/d during which reticuloruminal pH was < 5.8 . Time duration of pH < 5.5 was also increased in SARA-susceptible compared with the SARA-tolerant cows ($P = 0.05$) from d 5 to d 7 after parturition.

Peripartal Reticuloruminal Temperature Changes

Mean reticuloruminal temperature, from d 7 before to 8 d after parturition, was $39.24 \pm 0.02^\circ\text{C}$. No differences between breeds were observed ($P = 0.51$). Interestingly, also no differences between SARA-susceptible

and SARA-tolerant animals were recorded ($P = 0.63$). Overall, mean reticuloruminal temperature was affected by the day relative to parturition ($P < 0.01$; Figure 3). Daily mean reticuloruminal temperature was highest from d 7 to 2 prepartum and abruptly decreased from d 2 to 1 before parturition from $39.39 \pm 0.07^\circ\text{C}$ to $39.04 \pm 0.08^\circ\text{C}$. The time duration during which

the reticuloruminal temperature was $>39.5^\circ\text{C}$ was not affected by breed ($P = 0.65$) or SARA susceptibility ($P = 0.35$). Overall, the day relative to calving showed a marked influence ($P < 0.01$, Figure 3), showing higher durations of high temperature from d 7 to 2 prepartum. In accordance to mean reticuloruminal temperature, an abrupt decrease in time duration of temperature

Figure 1. Daily mean reticuloruminal pH from d 7 before to d 8 after calving in Simmental ($n = 9$) and Brown Swiss ($n = 4$) cows (a) and in cows classified as SARA susceptible ($n = 8$) and SARA tolerant ($n = 5$; b). The SARA-susceptible cows had a duration of reticuloruminal pH < 5.8 longer than 330 min/d at least during 1 of the first 8 d after parturition; SARA-tolerant cows had a duration of reticuloruminal pH < 5.8 under 330 min/d during the first 8 d after parturition. * indicates differences between groups at $P \leq 0.05$.

Figure 2. Time duration of reticuloruminal pH <6.0 (a) and <5.8 (b) from d 7 before to d 8 after calving in SARA-susceptible and SARA-tolerant cows. The SARA-susceptible cows had a duration of reticuloruminal pH <5.8 longer than 330 min/d at least during 1 of the first 8 d after parturition; SARA-tolerant cows had a duration of reticuloruminal pH <5.8 under 330 min/d during the first 8 d after parturition. * indicates differences between groups at $P \leq 0.05$.

>39.5°C occurred 1 d before calving (from 734 ± 109 min to 304 ± 107 min).

Feed Intake and Milk Yield

Total DMI was not influenced by breed (11.3 ± 0.8 vs. 9.6 ± 1.1 kg of DM/d in Simmental vs. Brown

Swiss cows, $P = 0.19$) or SARA susceptibility (Table 2). Total DMI increased with time after calving ($P < 0.01$; Figure 4a). During the 1 d postpartum, all cows consumed the entire allowance of early lactation TMR, whereas the DMI of close-up TMR was generally low in both groups of cows (Figure 4b). Overall DMI of the close-up TMR tended to be higher ($P < 0.10$) for

Figure 3. Effect of day relative to calving on mean reticuloruminal temperature and time duration of temperature >39.5°C.

SARA-tolerant cows compared with SARA-susceptible cows (Table 2), whereby the differences were pronounced from d 6 to 8 after parturition ($P < 0.05$, Figure 4b). No differences occurred with respect to the intake of the TMR for early-lactating cows in absolute DM amounts (Table 2) or in relation to the offered TMR (95.88 ± 6.7 vs. $84.55 \pm 9.2\%$ in SARA-susceptible and SARA-tolerant animals, respectively, $P = 0.33$), as well as for most nutrients and energy (Table

2). Nevertheless, the higher intake of the close-up TMR led to a tendency for higher NDF and ADF intake in SARA-tolerant cows compared with SARA-susceptible cows (Table 2). Average milk yield was higher ($P = 0.02$) in Simmental cows (30.4 ± 1.2 kg/d) compared with Brown Swiss cows (27.9 ± 1.3 kg/d, Figure 5a), but did not differ ($P = 0.26$) between SARA-susceptible (27.9 ± 1.3 kg/d) and SARA-tolerant (25.3 ± 1.8 kg/d, Figure 5b) cows.

Table 2. Average intake of DM and major nutrients during the first 8 d postpartum¹

Intake	SARA susceptibility			P-value ²			
	Susceptible	Tolerant	Pooled SEM	Day	Breed	Susceptibility	Susceptibility × day
DMI, kg/d							
Close-up TMR	2.38	5.20	0.35	<0.01	0.50	0.02	0.07
Lactation TMR	7.70	6.39	0.39	0.02	0.93	0.30	0.81
Overall	10.0	11.5	0.40	<0.01	0.19	0.37	0.13
Intake (kg/d; unless stated otherwise)							
CP	1.72	1.78	0.07	<0.01	0.42	0.78	0.31
NDF	3.66	4.61	0.18	<0.01	0.21	0.07	0.05
ADF	2.25	2.81	0.11	<0.01	0.24	0.08	0.10
NFC ³	3.52	3.70	0.14	<0.01	0.38	0.67	0.27
NE _L (MJ/d)	67.3	72.3	2.68	<0.01	0.25	0.58	0.19

¹Cows were classified as SARA susceptible (n = 8) and SARA tolerant (n = 5): SARA-susceptible cows had a duration of reticuloruminal pH <5.8 longer than 330 min/d at least during 1 of the first 8 d after parturition; SARA-tolerant cows had a duration of reticuloruminal pH <5.8 under 330 min/d during the first 8 d after parturition.

²Effect of measurement day after calving (n = 8), breed (9 Simmental and 4 Brown Swiss cows), and SARA susceptibility.

³Nonfiber carbohydrates = 100 – (% NDF + % CP + % ether extract + % ash).

Correlations Between Feed Intake and Reticuloruminal pH and Temperature

Total DMI and mean reticuloruminal pH showed a low correlation ($r = -0.19$, $P = 0.07$). Furthermore, no correlation was found between total DMI and time pH <5.8 ($r = 0.09$, $P = 0.41$). Interestingly, also NFC

intake and mean reticuloruminal pH showed low correlation between them ($r = -0.25$, $P = 0.02$), whereas no correlation was found between mean reticuloruminal pH and NDF intake ($r = -0.11$, $P = 0.31$). In addition, neither NFC nor NDF intake were correlated with the time pH <5.8 ($r = 0.16$, $P = 0.12$ and $r = -0.02$, $P = 0.82$ for NFC and NDF intake, respectively). Further-

Figure 4. Total DMI (a) and DMI of close-up TMR (b) from d 1 to 8 after calving in SARA-susceptible and SARA-tolerant cows: SARA-susceptible cows had a duration of reticuloruminal pH <5.8 longer than 330 min/d at least during 1 of the first 8 d after parturition; SARA-tolerant cows had a duration of reticuloruminal pH <5.8 under 330 min/d during first 8 d after parturition. * indicates differences between groups at $P \leq 0.05$.

more, no correlations were found between total DMI and mean reticuloruminal temperature ($r = -0.01$, $P = 0.92$) or between total DMI and time duration of temperature $>39.5^{\circ}\text{C}$ ($r = 0.10$, $P = 0.32$), or for the intake of NFC and NDF and the respective temperature variables ($r < 0.13$, $P > 0.10$).

Correlation Between Reticuloruminal pH and Temperature

Mean reticuloruminal pH and temperature showed only a low correlation between them ($r = 0.24$, $P < 0.01$). Furthermore, low correlations were found be-

Figure 5. Daily milk yield from d 1 to d 8 after calving in Simmental ($n = 9$) and Brown Swiss ($n = 4$) cows (a) and in cows classified as SARA-susceptible ($n = 8$) and SARA-tolerant ($n = 5$; b). The SARA-susceptible cows had a duration of reticuloruminal pH <5.8 longer than 330 min/d at least during 1 of the first 8 d after parturition; SARA-tolerant cows had a duration of reticuloruminal pH <5.8 under 330 min/d during the first 8 d after parturition. * indicates differences between groups at $P \leq 0.05$.

tween time duration of reticuloruminal temperature $>39.5^{\circ}\text{C}$ and time duration of pH <5.8 ($r = -0.24$, $P < 0.01$).

DISCUSSION

Reticuloruminal pH and SARA Responses

In the current study, changes in reticuloruminal pH and temperature dynamics during the periparturient period were investigated in periparturient dairy cows gradually switched from a forage-rich close-up diet to a concentrate-rich diet for early-lactating cows. A decrease in reticuloruminal pH starting from d 3 after parturition indicates an increased risk of SARA in cows shortly after calving. Our data also indicated differences among cows regarding the susceptibility to SARA. Indeed, SARA-susceptible cows showed markedly longer duration of pH <5.8 or <6.0 compared with SARA-tolerant cows despite their similar feeding management conditions, total DMI, and milk yield.

Depressed reticuloruminal pH in SARA-susceptible cows early postpartum could indicate more rapid ruminal fermentation compared with SARA-tolerant cows (Aschenbach et al., 2011), resulting in faster rate of formation of the VFA in the rumen fluid. Formation of VFA in the rumen is typically promoted by higher DMI and especially higher intake of easily fermentable carbohydrates such as rapidly degradable starch and sugars (Zebeli et al., 2008). Because both these variables were not higher in SARA-susceptible cows compared with the SARA-tolerant group, it is reasonable to assume that VFA generation was not the reason for such different SARA susceptibilities, as observed in this study.

Different susceptibilities to SARA may also suggest differences in the buffering capacity of ruminal VFA (Aschenbach et al., 2011), likely resulting in different regulatory mechanisms of the intraruminal pH among SARA-susceptible and SARA-tolerant cows. Ruminal buffering capacity is mainly affected by feed composition, saliva secretion, and the rate of VFA absorption across the rumen wall (Allen, 1997). We did not observe any difference in the intake of the TMR for early-lactating cows; however, SARA-tolerant cows consumed higher amounts of the fiber-rich close-up TMR. Although it is unlikely that this small difference in fiber intake can fully explain the strong variation in SARA susceptibility, the differing eating behavior between SARA-susceptible and -tolerant cows early postpartum is indicative of differing self-regulatory mechanisms of the intra-ruminal pH in these cows. It can be speculated that less forage intake might have decreased chewing time in the SARA-susceptible group. An overall reduction in the rumination time in cows around parturition

has recently been described by Calamari et al. (2014). In our study, the decrease of forage intake might have affected the rumination activity of SARA-susceptible cows more strongly than in the SARA-tolerant group. Because a reduced chewing time decreases the daily saliva output (Allen, 1997), this may lead to reduced rumen buffering and less capability to regulate pH in the rumen of SARA-susceptible cows.

Nevertheless, the intake of nutrients showed only a tendency for difference with respect to NDF and ADF intake between both groups, which was particularly pronounced on d 4 and 6 after parturition. Although a high NDF intake is known to stimulate chewing activity (Zebeli et al., 2008), this influence does not seem to fully explain the strong differences between SARA-susceptible and SARA-tolerant groups because no correlation was found between NDF intake and time of pH <5.8 . Furthermore, previous studies have shown that a higher chewing activity is not necessarily related to higher ruminal pH (Gao and Oba, 2014). On the other hand, great variation is present in eating and rumination behaviors as well as total eating and ruminating time among individual cows (Christensen and Fehr, 2000), and recently it has been shown that dairy cows tolerant to high-grain diets sort less against long particles compared with susceptible cows (Gao and Oba, 2014).

Reticuloruminal Temperature

The decrease of reticuloruminal temperature shortly before parturition is another finding of this study. This result concurs with previous reports that ruminal temperature (Cooper-Prado et al., 2011) and body temperature (Wrenn et al., 1958; Lammoglia et al., 1997) of cows decreased by 0.33°C or between 0.4 to 1.0°C before parturition, respectively. Although ruminal or reticular temperatures are about 0.5°C higher than rectal temperatures (Simmons et al., 1965), they have been shown to be effective measures of core body temperature (Hicks et al., 2001; Prendiville et al., 2002). The decrease in temperature shortly before parturition may be caused by endocrine and behavioral changes during the periparturient period. Lammoglia et al. (1997) observed that body temperature before the precalving decrease was influenced by the environmental temperature and the sex of the calf. Regarding the endocrine effects on prepartum decline in body temperature, progesterone is assumed to exert a thermogenic effect (Bobowiec et al., 1990; Kyle et al., 1998), as suggested by the correlation between progesterone in plasma and body temperature (Birgel et al., 1994). This is further supported by the greater body temperature during the last week of pregnancy and a decrease in temperature

1 to 2 d before parturition as observed in the present as well as in previous studies (Wrenn et al., 1958; Aoki et al., 2005).

Overall, the decrease in ruminal temperature the day before parturition may offer one reliable opportunity to predict parturition. This is of vital importance because about 50% of the calf deaths related to dystocia (Patterson et al., 1987) could be prevented by providing timely, correct obstetrical assistance. Frequent recording of body temperature may be required to detect the decrease in body temperature before parturition, to predict time of calving. Hence, the usage of rumen boluses and telemetry allows minimally invasive, frequent records or real-time records with minimal labor, and thus may improve prediction of the time of calving.

Besides temperature changes related to calving, it was shown that rumen temperature is negatively correlated with the rumen pH in lactating cows suffering from SARA (AlZahal et al., 2008). These authors found that rumen temperature between 39 to 41°C is critical for SARA diagnosis because it has a negative relationship with its corresponding pH. In contrast, low correlation was found between ruminal temperature and ruminal pH ($r = 0.24$) in the present study. Furthermore a low correlation was found between time duration of reticuloruminal temperature $>39.5^{\circ}\text{C}$ and pH <5.8 ($r = -0.24$). Thus, ruminal temperature readings do not seem to be an effective management tool to diagnose SARA in field conditions.

CONCLUSIONS

Overall, the results of the present experiment indicate an increased risk of susceptible cows to develop SARA early postpartum. The findings of high inter-animal variations suggest the need for monitoring and differentiated feeding management of cows during the transition period, whereby the SARA-susceptible cows may require particular attention regarding the feeding management and diet composition. Further research is warranted to enhance the physiological understanding of the underlying mechanisms for the individual differences in the tolerance to SARA and to establish feeding strategies to reduce the occurrence and detrimental effects of this metabolic disorder at an early phase postpartum. With regard to temperature measurements, the decrease in ruminal temperature the day before parturition may enable this noninvasive method as a management tool for prediction of parturition time.

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