Rumen temperature change monitored with remote rumen temperature boluses after challenges with bovine viral diarrhea virus and \textit{Mannheimia haemolytica}\textsuperscript{1,2}

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ABSTRACT: Remote rumen temperature monitoring is a potential method for early disease detection in beef cattle. This experiment was conducted to determine if remotely monitored rumen temperature boluses could detect a temperature change in steers exposed to bovine viral diarrhea virus (BVDV) and challenged with a common bovine respiratory disease pathogen, \textit{Mannheimia haemolytica} (MH). Twenty-four Angus crossbred steers (BW = 313 ± 31 kg) were allotted to 1 of 4 treatments: 1) no challenge (control); 2) challenge by a 72-h exposure to 2 steers persistently infected with BVDV; 3) bacterial challenge with MH; and 4) viral challenge by a 72-h exposure to 2 steers persistently infected with BVDV followed by bacterial challenge with MH (BVDV + MH). Remotely monitored rumen temperature boluses programmed to transmit temperature every minute were placed in the rumen before the time of exposure to steers persistently infected with BVDV. Rectal temperatures were taken before MH challenge (0) and at 2, 4, 6, 12, 18, 24, 36, 48, 72, and 96 h after MH challenge. Rumen temperatures were recorded 3 d before (−72 h; period of BVDV exposure) through 14 d after (336 h) MH challenge. Rumen temperatures were analyzed as a randomized complete block design with a 2 × 2 factorial arrangement of treatments and a first-order autoregressive covariance structure for repeated measures. A treatment × day interaction was observed for average daily rumen temperature \((P < 0.01)\). A treatment difference \((P < 0.01)\) was observed on d 0, when MH-challenged steers had greater rumen temperatures than steers not challenged with MH. There was no BVDV × day interaction \((P > 0.01)\). Rumen temperatures averaged every 2 h resulted in a BVDV × hour interaction \((P < 0.01)\) and an MH × hour interaction \((P < 0.01)\). The BVDV × hour differences occurred at h −18 to −14, 40 to 46, 110, 122, and 144 to 146 \((P < 0.01)\). The MH × hour difference occurred at h 4 to 24 \((P < 0.01)\). Maximum rumen temperature was increased \((P < 0.01)\) for BVDV (0.8°C), MH (1.2°C), and BVDV + MH (1.3°C) compared with the control. On average, rumen temperatures measured by the boluses at the same time points as the rectal temperatures were 0.13°C less than rectal temperatures, and the 2 body temperatures were highly correlated \((r = 0.89)\). Rumen temperature boluses appear to have potential as a tool for detecting temperature changes associated with adverse health events such as exposure to bovine respiratory disease and BVDV.

Key words: bovine respiratory disease, cattle, health, remote temperature monitoring, temperature

INTRODUCTION

The cattle industry loses millions of dollars annually to health-related performance and death loss in receiving cattle (Chirase and Greene, 2001). Bovine respiratory disease (BRD) is the most significant health problem in US stocker operations and feedlots (Duff and Galyean, 2007), and it continues to have a negative effect on economics, animal well-being, performance, and carcass quality. The organism frequently isolated in cases of bronchopneumonia fibrinous is \textit{Mannheimia haemolytica} (MH). One of the many precursors to respiratory tract disease in feedlot cattle is bovine viral diarrhea virus (BVDV; Fulton et al., 2000). Cattle persistently infected (PI) with BVDV are a major beef industry concern because the virus may lead to decreased
performance and economic returns while increasing the susceptibility to other diseases such as BRD.

Diseases such as BVDV and BRD are commonly detected by observed depression, lack of fill, cough, altered gait, ocular or nasal discharge, or general physical weakness (Gardner et al., 1999; Berry et al., 2004). After clinical signs are observed, illness is supported objectively by an increased body temperature (usually determined by a rectal thermometer) reaching 40.0 to 42.2°C (Baker and Merwin, 1985; Gardner et al., 1999; Berry et al., 2004). However, Wittum et al. (1996) observed lung lesions in calves managed from birth and concluded that current methods of detecting BRD for treatment are not adequate to prevent production losses and that improved methods are needed. Remote means of detecting increased body temperature related to disease could lead to simple, more rapid, and more reliable disease detection. Improved disease detection and appropriate treatment may decrease the severity of illnesses and minimize decreased performance and carcass merit. The objective of this study was to determine the efficacy of remotely monitored rumen temperature boluses to determine core body temperature in calves exposed to BVDV and challenged with a common BRD pathogen (MH).

**MATERIALS AND METHODS**

All procedures were reviewed and approved by the Oklahoma State University Animal Care and Use Committee.

**Animals**

This study was conducted at the Oklahoma State University Nutrition Physiology Research Center in Stillwater. Twenty-four Angus crossbred steers (initial BW = 313 ± 31 kg) were used in 2 blocks that lasted 17 d. Steers were 6 to 8 mo old, came from the Oklahoma State University South Range Research Center, and had been vaccinated with Ultra Choice 7 (Pfizer Animal Health, Exton, PA) at 3 and 7 mo of age. Before allotment, all animals were considered clinically healthy and seronegative to all pathogens involved in the study, as determined by paired serum samples collected 14 d apart (Buriaga-Robles et al., 2010b). Subjective clinical scores were recorded each day after the challenge (Buriaga-Robles et al., 2010b). No steers exhibited visual signs of BRD that warranted therapeutic intervention.

Twenty-four steers were allotted to 1 of the following treatments: 1) no challenge (CON), 2) challenge by a 72-h exposure to 2 PI BVDV steers; 3) bacterial challenge with MH; and 4) viral challenge by 72-h exposure to 2 PI BVDV steers followed by bacterial challenge with MH (BVDV + MH). For a 72-h period before the MH challenge, treatment 2 and 4 steers were exposed to 2 calves confirmed as persistently infected with BVDV1b in a 6 × 11 m pen at the Wil- lard Sparks Beef Research Center at Oklahoma State University, Stillwater. Testing of the PI animals was performed using immunohistochemistry, as described in Fulton et al. (2006). The PI subtype was determined by sequencing the 5′-untranslated region. During this 72 h, treatment 1 and 3 steers remained in 3.7 × 3.7 m stalls at the Nutrition Physiology Research Center. After BVDV exposure, calves were returned to the Nutrition Physiology Unit 12 h before MH challenge. At time 0, all steers were intratracheally challenged using 60 mL of PBS solution, with or without 6 × 10^10 cfu of MH serotype 1. M. haemolytica was reconstituted and grown as described by Mosier et al. (1998). Inoculation with the MH culture or PBS solution was performed as described by Dowling et al. (2002), with some modifications. Briefly, steers were restrained and a bronchoalveolar lavage tube (Bivona Medical Technology, Gary, IN) was inserted into the ventral meatus of a nostril, passed into the trachea, and placed within 2 to 3 cm of the tracheal bifurcation. The challenge material was then delivered such that material would be allowed to enter both lungs. Steers were observed for any adverse effects of the challenge procedure itself. The bronchoalveolar lavage tube was sterilized with weak chlorhexidine solution, rinsed with saline, and reused only for animals in the same treatment. Challenge with MH occurred on the same day for all appropriate treatment groups, beginning at 0800 h. To facilitate sample collection, steers were blocked by BW into 2 groups of 12, and the challenge procedures and sample collections for each BW block were staggered by a 2-wk interval. Steers remained in 3.7 × 3.7 m stalls except for d 0 to 4 and d 7 to 11, when they were placed in metabolism stalls for additional sampling (Buriaga-Robles et al., 2010a,b). Steers were grouped by treatment in the metabolism stanchions and stalls, with 2 empty stanchions and stalls between each treatment group, and were not allowed to share water sources. In addition, steers were housed such that air flow and animal-handling patterns progressed from CON to BVD and then to MH steers to reduce potential unintended exposure to MH. Steers had free-choice access to water and were offered feed for ad libitum intake at 0800 and 1700 h. The diet (DM basis) contained 46% dry-rolled corn, 9% dried corn distillers grains, 40% alfalfa hay, 1% liquid supplement, and 4% dry supplement and was formulated to meet or exceed nutrient requirements (NRC, 2000; Buriaga-Robles et al., 2010a). The diet contained 0.018% (DM basis) monensin (Rumensin 80, Elanco Animal Health, Greenfield, IN).

**Data Collection**

Rumen temperature boluses (SmartStock LLC, Pawnee, OK) were orally administered before exposure to PI BVDV steers by using a custom-made balling gun. The electronic data collection system consisted of 4 components: 1) the temperature-sensor bolus contained inside the rumen of the animal, 2) 2 antennas with...
Statistical Analyses

The experiment was designed as a randomized complete block with a 2 × 2 factorial arrangement of treatments. Animal served as the experimental unit. Antibody titer data demonstrated that all individual steers exposed as a group to PI BVDV1b steers contracted the infection and mounted an independent immune response, and that steers not exposed to the PI steers did not mount an immune response (Burciaga-Robles et al., 2010b). Rumen temperatures were analyzed using repeated-measures analysis of the MIXED procedure (SAS Inst. Inc., Cary, NC), with a first-order autoregressive covariance structure. The covariance structure was selected by subjecting the model to multiple covariance structures, and the best fit model was selected to contain the covariance structure that yielded the smaller Akaike’s and Schwarz’s Bayesian criteria based on their −2 res log-likelihood. The model for all variables included the main effects of BVD, MH, BVD × MH, and all possible interactions with time. When a BVD, MH, or BVD × MH × time interaction was significant (P < 0.01), the slice output option of SAS was used to determine the time points at which treatments were different. A loss of data occurred from −72 to −24 h during block 1 for calves exposed to BVDV because of an equipment malfunction at the location steers were exposed to the PI BVDV calves. Statistical analysis and graphs from this time period and treatments only represent block 2. The exact time point that each rectal temperature was taken was recorded. The single 1-min rumen temperature that occurred at that time point was then identified for use in rectal to rumen temperature measurements. The Pearson CORR procedure of SAS was used to determine how rumen and rectal temperatures related to each other. Rumen and rectal temperatures were then fitted to a best-fit linear regression line.

RESULTS

There were no BVDV × MH × time interactions (P > 0.01) for rumen temperature data. Average daily rumen temperature resulted in an MH × day interaction (P < 0.01; Figure 1). A difference (P < 0.01) was observed on d 0 (MH challenge day), when rumen temperatures of MH-challenged steers were greater than those of control steers. There was no BVDV × day interaction (P > 0.01; data not shown). There were MH × hour and BVDV × hour interactions (P < 0.01) for rumen temperature averaged every 2 h. The BVDV × hour differences occurred at h −18 to −14, 40 to 46, 110, 122, and 144 to 146 (P < 0.01; Figure 2). The MH × hour difference occurred at h 4 to 24 h (P < 0.01; Figure 3). Rumen temperatures averaged every 2 h peaked at 8 h for MH (41.2°C). The maximum rumen temperature was increased (P < 0.01; Table 1) for steers in the BVDV (0.8°C), MH (1.2°C), and BVDV + MH (1.3°C) treatments compared with the CON treatment. No treatment differences were observed in the minimum, average, or range of rumen temperatures. Rectal temperatures were correlated with rumen temperatures (r = 0.89; P < 0.01) at the 11 time points, with rectal temperatures averaging 0.13°C more than rumen temperatures. Rectal temperatures ranged from 38.3 to 42.3°C, and rumen temperatures ranged from 38.0 to 42.4°C. A linear relationship was found between rumen and rectal temperatures, with r² = 0.80 (Figure 4).

DISCUSSION

Rectal temperature is a key indicator of illness that is often difficult to obtain in many production settings because it requires moving the animal from its pen or pasture to a handling facility for restraint. Despite this limitation to using rectal temperatures, a minimal amount of research has been conducted to determine alternative methods of temperature recording for the purpose of health detection. Most alternative temperature detection methods have been used to determine the effects of hot (Lefcourt and Adams, 1996; Hahn, 1999; Davis et al., 2003b) or cold (Lefcourt and Adams, 1998) temperatures, stress-inducing activities (Mader et al., 2005), and growth promotants (Mader and Kreikemeier, 2006) on the core body temperature estimation of the animal. Studies have compared the relationship of alternative temperature measurement devices (Hahn et al., 1990), including intraruminal devices (Bhattacharya and Warner, 1968; Hicks et al., 2001; Bewley et al., 2008a), with rectal temperature. Hicks et al. (2001) showed that temperature readings from a bolus placed in the cannula of a rumen-fistu-
lated Holstein cow had the same average temperature as rectal temperature measurements, of 38.7°C. Their rumen temperature average was similar to the 38.9°C reported for control calves in the present study. The rectal and rumen body temperature difference observed in the present study is similar to results using other methods to determine core body temperature. Davis et al. (2003a) reported the average tympanic, peritoneal

**Figure 1.** Average daily rumen temperature of calves challenged intratracheally with $6 \times 10^9$ cfu of *Mannheimia haemolytica* serotype 1 (MH) compared with non-MH-challenged calves (no MH). Challenge with MH was conducted at the beginning of d 0. The values plotted represent least squares means of the mean calculated for 12 animals per experimental group on d −1 to 13 and for 9 experimental animals on d −3 and −2. a,bMeans within a day with unlike letters differ ($P < 0.01$).

**Figure 2.** Rumen temperature, averaged every 2 h, of calves exposed for 72 h to 2 steers persistently infected with bovine viral diarrhea virus type 1b (BVDV) compared with non-BVDV-challenged calves (no BVDV). Hour 0 is equal to *Mannheimia haemolytica* (MH) challenge. The values plotted represent least squares means of the mean calculated for 12 animals per experimental group. a,bMeans within an hour with unlike letters differ ($P < 0.01$). Time points for BVDV from h −72 to −24 in block 1 were lost because of equipment failure, and only data for time periods after h −24 are presented. Time points for 170 to 336 h were not significant ($P > 0.01$) and are not presented.
cavity, and rectal temperature of 4 steers during a 24-h period. Tympanic and peritoneal temperatures were, respectively, 0.1 and 0.2°C less than the rectal temperature. Prendiville et al. (2002) reported, in a study using 8 steers, no significant difference between tympanic and rectal temperatures. These authors also reported that during a 5-d period, rumen bolus temperatures were significantly greater than rectal and tympanic temperatures, with average temperatures of 39.0°C (rumen), 38.4°C (rectal), and 38.2°C (tympanic). Previous research with rumen temperature boluses indicated that rumen temperature could range from 0 to 0.6°C more than rectal temperature, whereas the present study showed that rumen temperature averaged 0.13 ± 0.38°C less than rectal temperature at coinciding time points, with \( r = 0.89 \).

It has been demonstrated (Darcy and Kurtenbach, 1968; Beatty et al., 2008) that rumen temperatures generally follow the same pattern as temperatures at other core body locations, with the exception that water consumption will create decreases in rumen temperature that can last up to 3.5 h, depending on the quantity and temperature of the water consumed (Brod et al., 1982; Bewley et al., 2008b). Bewley et al. (2008a) compared rumen and reticular temperatures in dairy cows and concluded that the relationship between the 2 temperature measures was strongly correlated (\( r = 0.645 \)) and that it varied by season, milking, housing

### Table 1. Effect of *Mannheimia haemolytica* and bovine viral diarrhea virus challenge on rumen temperature average, minimum, maximum, and range (°C) 72 h before and 336 h after *M. haemolytica* challenge

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>BVDV</th>
<th>MH</th>
<th>BVDV + MH</th>
<th>SEM²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>38.9</td>
<td>39.0</td>
<td>39.0</td>
<td>39.1</td>
<td>0.1</td>
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<tr>
<td>Minimum</td>
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<td>34.2</td>
<td>34.3</td>
<td>34.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>40.3⁵</td>
<td>41.1⁶</td>
<td>41.5⁶</td>
<td>41.6⁶</td>
<td>0.1</td>
</tr>
<tr>
<td>Range</td>
<td>6.0</td>
<td>6.9</td>
<td>7.2</td>
<td>7.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

⁵,⁶Within row, numbers with different superscripts differ (\( P < 0.01 \)).

¹Treatments: control = no challenge; BVDV = exposed to bovine viral diarrhea virus type 1b; MH = challenged intratracheally with \( 6 \times 10^9 \) cfu of *M. haemolytica* serotype 1; BVDV + MH = exposed to BVDV type 1b and challenged intratracheally with \( 6 \times 10^9 \) cfu of *M. haemolytica* serotype 1.

²Pooled SE of the least squares means.

Figure 3. Rumen temperature, averaged every 2 h, of calves challenged intratracheally with \( 6 \times 10^9 \) cfu of *Mannheimia haemolytica* serotype 1 (MH) compared with non-MH-challenged calves (no MH). Hour 0 is equal to the MH challenge. The values plotted represent least squares means of the mean calculated for 12 animals per experimental group. a,bMeans within an hour with unlike letters differ (\( P < 0.01 \)). Time points for 50 to 336 h were not significant (\( P > 0.01 \)) and are not presented.
AlZahal et al. (2009) compared an in situ system that measured temperature and pH with an attached reticular temperature bolus from the same manufacturer as used in the current experiment. As dairy cows were fed an increased concentrate diet, the in situ system detected changes in temperature as the diet concentrate component increased that were not detected by the bolus. This was most likely due to the temperature sensor of the bolus being encased within a solid polymer bolus that did not respond to the short-term temperature changes detected by an exposed sensor. However, the relationship between temperature and low rumen pH was similar between temperatures from the in situ system and bolus measures. These comparisons of rumen, rectal, and other core temperatures do indicate that they tend to respond similarly to influencing factors, although they may have variation in the magnitude of response to events.

Rumen temperature boluses are potentially more advantageous for the commercial feedlot industry or with a larger number of animals for a longer period of time than the tympanic temperature probes and implanted or injected temperature transponders, which are temporary or labor and cost intensive to administer. However, with water and other factors influencing rumen temperature readings, it was unclear if large enough increases in rumen temperature occur and are detectable during adverse health events. The current study indicates that rumen temperature boluses detected an immediate response to the MH challenge, whereas exposure to PI BVDV steers caused cyclical temperature increases during and after exposure. Response to the MH challenge increased daily average and maximum ruminal temperatures to approximately 1.2°C greater than those of control calves, and then daily average temperatures decreased to control temperatures by 24 h. Rectal temperatures in response to the MH challenge reported by Burciaga-Robles et al. (2010b) increased by approximately 2°C and then returned to control temperatures by 36 h. Confer et al. (2009) and Corrigan et al. (2007) also reported this response in rectal temperature in response to an MH challenge. In the current experiment, 2-h averaged temperature measures at points that were significantly different with BVDV exposure were increased by approximately 0.6°C, whereas maximum temperature increases were 0.8°C because of BVDV exposure. Rectal temperatures in response to the BVDV exposure reported by Burciaga-Robles et al. (2010b) were approximately 0.3 to 0.5°C greater than those of nonexposed calves during a period from 36 to 72 h after MH challenge. In a BVDV type 2 challenge, Kelling et al. (2007) reported that nonvaccinated animals had greater rectal temperatures on d 9 to 11 after intranasal challenge compared with a vaccinated group. Calves challenged with noncytopathic type 1 BVDV (Gånheim et al., 2005) had a mild fever (>39.5°C) from d 1 through 5 after viral inoculation compared with nonchallenged controls. These results suggest that rumen temperature measurements are capable of detecting temperature changes in response to both MH and BVDV challenges similar to those that have been reported for rectal temperature.

Results in this experiment were detected with the measurements being transmitted every minute, with a
receiving rate of greater than 90%. Before being practical for industry applications, evaluations will need to determine an appropriate measurement rate that allows detection of health-related temperature events, minimizes unnecessary data collection, and will extend the life of boluses or allow for reduced power requirements. This need was demonstrated by Small et al. (2008), who challenged beef heifers with a lipopolysaccharide endotoxin. These researchers used a reading system in which heifers passed a reading panel to be read. When heifers were moved passed the panel on a schedule, the panel detected a temperature change in relation to the challenge, but not when heifers were allowed to pass the reading panel at will.

This research has demonstrated that remote-monitored rumen temperature boluses provide temperature results that are highly correlated with rectal temperatures over a normal biological range of temperatures and that they have the potential to be a viable means of detecting adverse health events in cattle. Morbid animals are normally identified by visual signs, supported objectively by rectal temperature results. Remotely obtained rumen temperature measurements have an advantage over rectal temperature measurements in that rumen temperatures are easier to obtain and could potentially result in detection before clinical signs occur. Improved detection of adverse health events may result in decreased severity of morbidity and reduced mortality in the cattle-receiving and cattle-feeding industry. This could reduce the impact of adverse health effects on animal performance and could improve economics and animal well-being. Additional research will be necessary to determine if the use of rumen temperature-monitoring boluses will allow for detection of naturally occurring disease in production settings. Any improvements in detection will need to be coupled with effective management that results in decreased treatment costs or decreased severity of the disease, which results in an economic advantage to cattle producers.

**LITERATURE CITED**


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