Feeding behavior as an early predictor of bovine respiratory disease in North American feedlot systems

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ABSTRACT: Bovine respiratory disease (BRD), which can cause substantial losses for feedlot operations, is often difficult to detect based solely on visual observations. The objectives of the current study were to determine a BRD case identification based on clinical and laboratory parameters and assess the value of feeding behavior for early detection of BRD. Auction-derived, mixed-breed beef steers (n = 213) with an average arrival weight of 294 kg were placed at a southern Alberta commercial feedlot equipped with an automated feed bunk monitoring system. Feeding behavior was recorded continuously (1-s intervals) for 5 wk after arrival and summarized into meals. Meals were defined as feeding events that were interrupted by less than 300 s nonfeeding. Meal intake (g) and meal time (min) were further summarized into daily mean, minimum, maximum, and sum and, together with frequency of meals per day, were fit into a discrete survival time analysis with a conditional log–log link. Feedlot staff visually evaluated (pen-checked) health status twice daily. Within 35 d after arrival, 76% (n = 165) of the steers had 1 or more clinical signs of BRD (reluctance to move, crusted nose, nasal or ocular discharge, drooped ears or head, and gaunt appearance). Whereas 41 blood samples could not be processed due to immediate freezing, for 124 of these steers, complete and differential blood cell count, total serum protein, plasma fibrinogen, serum concentration of haptoglobin (HP), and serum amyloid A (SAA) were determined. The disease definition for BRD was a rectal temperature ≥ 40.0°C, at least 2 clinical signs of BRD, and HP > 0.15 mg/mL. It was noteworthy that 94% of the 124 steers identified by the feedlot staff with clinical signs of BRD had HP > 0.15 mg/mL. An increase in mean meal intake, frequency, and mean inter-meal interval was associated with a decreased hazard for developing BRD 7 d before visual identification (P < 0.001). Furthermore, increased mean mealtime, frequency, and mean inter-meal interval were associated with a decreased BRD hazard up to 7 d before feedlot staff noticed clinical symptoms (P < 0.001). In conclusion, mean intake per meal as well as mean meal time and frequency of meals could be used to predict the hazard of BRD in feedlot cattle 7 d before visual detection and could be considered in commercial feedlot settings once a predictive algorithm has been developed.

Key words: bovine respiratory disease, early detection, feeding behavior, feedlot cattle, haptoglobin


INTRODUCTION

Bovine respiratory disease (BRD) remains the most important health concern in the feedlot industry (Smith, 1998; Jim, 2009; Schneider et al., 2009). Diagnosis of BRD in feedlots typically relies on visual appraisal, with low sensitivity and specificity (62 and 63%, respectively; White and Renter, 2009). Two major acute phase proteins (APP) have been used to verify inflammation and tissue damage in
cattle with BRD (Nikunen et al., 2007; Ceciliani et al., 2012). Haptoglobin (HP) had a sensitivity of 64% and specificity of 71% (Svensson et al., 2007) and serum amyloid A (SAA) had a clinical sensitivity of 100% and specificity of 46% (Horadagoda et al., 1999).

To improve disease detection, tools have been developed to objectively measure health and well-being of cattle automatically (Theurer et al., 2012). Because fever reduces feed intake in mammals (Hart, 1988), feeding behavior during the first days after arrival has been compared between BRD-affected and healthy cattle. Daily feeding time was shorter in sick cattle in the first days on feed (DOF; Sowell et al., 1999; Buhman et al., 2000).

Feeding behavior systems record feeding times only (e.g., Ubisense Series 7000 Compact Tag; Ubisense, Denver; Theurer et al., 2013) or include load cells that measure feed disappearance (intake, e.g., GrowSafe Systems, Airdrie, AB, Canada; Schwartzkopf-Genswein et al., 2011). Reports quantifying changes in feeding behavior compared to the time of visual detection of disease are limited (Quimby et al., 2001; Silasi 2007) but could provide the insight needed for commercial development of automated disease-detection systems.

The objectives of the current study were to determine a BRD case identification based on clinical and laboratory parameters and evaluate the associations between timing of visual detection of BRD and daily feeding behavior (i.e., feeding times as well as meal intake and frequency). We hypothesized that both feeding time and intake variables can be used to detect BRD earlier than visual observation.

MATERIALS AND METHODS

All procedures were performed in accordance with the regulations of the Canadian Council on Animal Care (CCAC, 2009) and were approved by the University of Calgary Veterinary Sciences Animal Care Committee.

Study Design, Animals, and Housing

The study included 213 auction-derived, spring-born, mixed-breed steers with an average arrival weight of 294 kg. Steers were delivered on November 2 and 3, 2010 to a typical mid-sized (1-time capacity of 15,000 cattle) commercial feedlot ~50-km north of Calgary, AB, Canada. Detailed health and feeding data were collected for 35 d after arrival. Incoming steers were managed according to the feedlot’s herd health induction protocol and were allocated to a single pen equipped with an automated recording system for individual feeding behavior (GrowSafe Systems Ltd., Airdrie, AB, Canada). At induction, all steers were ear-tagged with a radio frequency transponder (Allflex, Dallas/Ft. Worth, TX), which was also used as a unique identifier for the feeding behavior recording system. Another ear-tag was used as feedlot identification. Steers were treated with 150 mg of ivermectin (Ivomec pour-on; Merial, Baie d’Urfe, QC, Canada) for internal and external parasites. The induction protocol also included vaccinations against clostridial diseases (Vision 7, Merck, Kirkland, QC, Canada), Haemophilus somnus (Somnu-star Ph, Novartis, Mississauga, ON, Canada), bovine herpes virus-1, bovine viral diarrhea virus types 1 and 2, parainfluenza-3 virus, and bovine respiratory syncytial virus (StarVac 4 plus, Novartis, Mississauga, ON, Canada). Long-acting oxytetracycline 20 mg/kg BW (Bio-mycin 200; Boehringer-Ingelheim, Burlington, ON, Canada) was administered as a metaphylactic treatment against BRD.

The steers were housed in a dirt-floor pen (50 × 60 m; 14 m² of pen space per steer). Feed was delivered daily at 0700 h as a total mixed ration (49.27% DM) and contained 52.0% barley silage and 35.3% tempered barley, 10% wet distillers grain, and 2.7% supplements. Feed and fresh water were available ad libitum.

Case Definition and Treatment

True BRD cases were identified at their first incidence during the first 35 days on feed (DOF; observation period) as follows: every morning and noon, 1 of 2 experienced feedlot employees separated steers visually suspicious for BRD from their pen mates (“pulling”). Feedlot employees used the following signs as indicators to support the diagnosis of BRD and recorded them in a feedlot management program: reluctance to move, crust ed nose, nasal or ocular discharge, drooped ears or head, and gaunt appearance. Pulled steers were handled through a chute in the hospital area of the feedlot for physical examination, measuring and recording rectal temperature, and treatment. Three blood tubes (7-mL volume/tube; 1 EDTA and 2 serum tubes) were collected via jugular venipuncture to measure complete blood cell count, serum HP, and APP.

Steers were treated if their rectal temperature was ≥40.0°C or if temperature was <40.0°C but severe signs of sickness (i.e., labored breathing, severe depression) were present. At the time of first treatment, 9 mg/kg BW enrofloxacin (Baytril; Bayer, Toronto, ON, Canada) was administered s.c. according to the manufacturer’s recommendations. If clinical signs reappeared (or were still apparent) after 4 d, 40 mg/kg BW florfenicol (Nuflor; Merck, Kirkland, QC, Canada) was administered s.c. as a second treatment. Steers were returned to their home pen without treatment if temperature was <40.0°C and no severe sickness was noticed in the treatment chute.

The specific requirements for inclusion in the analysis as true BRD on the pulling day (“case”) were: pulled...
with ≥2 clinical signs of BRD, rectal temperature > 40°C, and HP > 0.15 mg/mL (Fig. 1). At all times when cattle appeared healthy they were used as “control,” with the exception of 7 d before and 7 d past the pulling event. This period was chosen according to results from previous research that suggested highest predictive values of feeding behavior up to 7 d before pulling (Silasi, 2007) and indicated continuing altered feeding behavior after treatment in other infectious diseases (Yeiser et al., 2012).

**Laboratory Analyses**

Whole-blood samples were submitted to a reference laboratory (Antech Diagnostics Ltd., Calgary, AB, Canada) the day they were collected from pulled steers to determine complete blood cell count (CBC), total serum protein (TP), and plasma fibrinogen (FB). Due to extreme weather conditions, including freezing of blood samples immediately after drawing or the inability to drive from Calgary to the feedlot during those weather conditions, 41 blood samples could not be processed.

Serum blood samples were centrifuged within 24 h after they were collected, aliquoted, and stored at -20°C pending determination of SAA and HP. Both APP analyses were performed using commercially available ELISA kits (Tridelta Development Ltd., Maynooth, Ireland). Serum was thawed and analyzed at room temperature and diluted (1:500 ratio) for the SAA assay. Results were calculated using the ELISA standard curve, reading the absorption at 450 nm and transferring the values into mg/mL or mg/mL, with a working range of 9.4 to 150 mg/mL for SAA and 0.05 to 3 mg/mL for HP. Mean interassay CVs for HP and SAA were 7.2 and 9.4%, respectively, whereas the intraassay CVs were <6.3 and <7.5%, respectively.

A laboratory internal reference range was created for HP and SAA from serum samples of healthy mixed-breed weaned steers from 2 research institutions (n = 16 and 40) and 1 commercial feedlot (n = 78) also located in Western Canada. None of the reference cattle received any treatments from 6 wk before to 6 wk after the sampling date. As suggested by Horn et al. (1998), extreme outliers (third quartile +1.5 × interquartile range) were excluded from the healthy range. Reference intervals for HP and SAA were defined using the upper 97.5th percentile as the cutoff (Horn et al., 1998).

**Feeding Data Collection**

Feeding behavior records were collected continuously from the day of arrival to the feedlot to 35 d after arrival, when the hazard for first pulling events reached a nadir (Fig. 2). An electronic monitoring system recorded presence of the steers at the feed bunk by scanning the radio frequency ear-tag at 1-s intervals, enabling measurement of individual bunk attendance frequency, feeding time (s), and intake (g) during the visit (Growsafe Ltd., Airdrie, AB, Canada). The pen was equipped with 32 individual feeding stalls measuring 0.97 × 1.25 × 0.90 m. The system has been described and validated (Schwartzkopf-Genswein et al., 1999; Basarab et al., 2003). All feed intake data presented were measured on an as-fed basis. Feeding time, frequency, and intake were summarized into meals. A meal was defined as a feeding event that was not interrupted by >300 s of nonfeeding, based on survival analysis (de Haer and Merks, 1992) and a previous study by Schwartzkopf-Genswein et al. (2011). Meal time (s) and meal intake (g) were summarized daily into sum, mean, minimum, and maximum values for each steer over the entire trial. Frequency was considered as number of meals per day (Table 1).

**Statistical Analysis**

Statistical analyses were performed using Stata Version 13.1 (StataCorp LP, College Station, TX). The unit of observation was the steer. The significance level was set at a P-value of 0.05, and P-values ranging from 0.05 to 0.10 were regarded as trends. Feeding data of all 213 animals were evaluated (individual-animal basis) for biologically unexplainable and missing data. Nine steers were excluded due to inconsistent feeding records with >4 consecutive days of missing data.
The pulled population was described on the day of pulling using traditionally used laboratory parameters (CBC, differential blood count, TP, and FB). Results were categorized as within or outside the reference range.

A model was created for each of the 7 d before first pulling to assess when and if BRD can be detected earlier in comparison to pulling using daily summarized meal time, between meal time, meal intake, and meal frequency.

To account for the changing number of steers at risk of BRD over time, discrete time hazard models were used to predict BRD. Proportional hazards were calculated with a complementary log-log link, reflecting the underlying continuous metric for time. The changing hazard throughout the 35 DOF was accounted for by including a 4th-order polynomial of DOF (Singer and Willett, 2003). For steers that were never treated throughout the 35-d observation period, all days were labeled “control.” Additionally, the days up to 7 d before pulling and from 8 d past pulling were labeled “control” in the steers with BRD if no further treatments were applied to the steer. The day before BRD according to our definition was labeled “case” in the dataset. All other days between −8 and +8 relative to pulling were excluded (Fig. 3). Data from steers that were pulled but did not meet the BRD case definition were also excluded from the analyses. Relapses and retreats were not included in the analysis, as blood was only drawn from first-pull cattle.

For each of the 7 d before pulling, 2 separate model datasets were analyzed to account for different monitoring abilities in feeding behavior–recording systems. The first model set included only time measures (i.e., mean, minimum, maximum, sum of meal time, and inter-meal interval) and frequency of meals per day, whereas the second model set included all time measures and summarized meal intake variables (g; i.e., mean, minimum, maximum, sum of intake). Individual animal probabilities to be visually detected were predicted using the models. The cutoff for feeding behavior–based identification was a probability exceeding the daily incidence of visually based BRD identification. With no true gold standard available to define true BRD, sensitivity and specificity could not be defined. However, the percentages of visually detected steers that were detected based on feeding behavior and visually undetected steers that were also not detected based on feeding behavior were calculated as an estimate of detection accuracy.

Before model fitting, a correlation matrix was fit to all feeding-behavior predictors to avoid multicollinearity. Variables with an $r > 0.70$ were assessed in a univariate analysis with the outcome variable BRD; the variable with the lowest impact was not included in the model. Correlations were high between mean feeding time per meal and the longest meal event ($r = 0.71$), mean feed intake per meal and the largest meal ($r = 0.73$), and smallest and shortest meal ($r = 0.83$). Additionally, because sum is the product of mean and frequency, both means and sums were analyzed in univariate analysis and the variable with the stronger effect on BRD was chosen. All other variables were included in the first model and stepwise eliminated if $P > 0.05$. Confounding was considered present if 1 or more coefficients changed by $>20\%$ when removing a variable. There was no evidence for confounding by any of the excluded variables. The best fit was as-
Feeding behavior predicts respiratory disease

Assessed with Akaike Information Criterion. To account for hazard change over the observation period, DOF were modeled as a 4th-order polynomial (Dohoo et al., 2009). The results can be interpreted as follows: hazard ratio below 1 indicates decreased hazard throughout the observation time with a 1-unit increase in the variable; conversely, a hazard ratio above 1 indicates increased hazard with a 1-unit increase in the variable.

RESULTS

Laboratory Results

Median SAA was 18.67 mg/mL (interquartile range [IQR]: 4.85 to 38.02 mg/ml) with a 97.5th percentile at 80.31 mg/mL. Median HP in the laboratory internal reference group was 0.08 (IQR: 0.06 to 0.10 mg/mL) with the 97.5th percentile at 0.15 mg/mL. Ninety-four percent of the pulled population had HP values >0.15 mg/mL. A total of 51.8 and 83.9% of cases diverged from the laboratory-provided reference range in the neutrophil counts or the red blood cell count, respectively (Table 2).

Case Identification

Of the entire study population, 165 (77%) steers were pulled at least once, including 9 steers with incomplete feeding records and 41 steers with missing blood samples. Feedlot staff re-treated 42 (40%) and 11 (37%) of the first-treated steers with a rectal temperature ≥ 40.0°C and < 40.0°C, respectively. Seventeen steers (58%) that were pulled but not treated at first pulling were subsequently pulled again and required treatment.

Sixty-six steers met the case definition for BRD, whereas 47 steers were not pulled during the first 35 d (controls). The BRD hazard on each given day was 2.15%.

Bovine Respiratory Disease Prediction with Intake Variables

Throughout the 7 d before pulling, BRD hazard decreased with increasing mean intake per meal ($P < 0.001$), frequency ($P < 0.001$), and inter-meal interval ($P < 0.001$) in the model including feed intake measures. Throughout the entire 35-d period, BRD hazard decreased between 29% (SEM 4%) and 24% (SEM 3%) for steers with a 100-g increase in intake per meal varying per day before pulling. Furthermore, the smallest meal (minimum intake) was a significant predictor 2 d before pulling ($P = 0.02$), increasing the BRD hazard by 31% (SEM 15%) with an increase of 100 g in the minimum meal size. When feed intake variables were available, an increase in frequency by 1 meal per day resulted in a reduction of the BRD hazard between 11% (SEM 2%) and 18% (SEM 4%) in the week before pulling.

Five days before visual detection, 82% of the cases were detected based on intake variables using the probability of daily visual detection (2.15%) as cutoff and 78% of visually healthy steers were classified healthy. Between 1 and 3 d prior to visual detection, 80 to 81% of the cases were predicted as BRD cases by the survival model and 76 to 79% of the healthy population was classified healthy.

Bovine Respiratory Disease Prediction with Time Variables

Mean feeding time ($P < 0.001$), frequency ($P < 0.001$), and inter-meal interval ($P < 0.001$) were significant predictors throughout the week before pulling in the model set without intake measures. Additionally,

### Table 1. Descriptive statistics of feeding behavior variables for steers between d 7 and d 1 before pulling and steers that were visually healthy during the entire 35-d period

<table>
<thead>
<tr>
<th>Item</th>
<th>d−7</th>
<th>d−6</th>
<th>d−5</th>
<th>d−4</th>
<th>d−3</th>
<th>d−2</th>
<th>d−1</th>
<th>Healthy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean intake, 100 g</td>
<td>4.2 (2.8)</td>
<td>4.7 (3.1)</td>
<td>5.2 (3.1)</td>
<td>5.4 (3.2)</td>
<td>5.3 (3.1)</td>
<td>5.3 (3.2)</td>
<td>5.1 (3.0)</td>
<td>10.0 (5.2)</td>
</tr>
<tr>
<td>Minimum (SD)</td>
<td>0.3 (0.7)</td>
<td>0.3 (1.1)</td>
<td>0.1 (0.4)</td>
<td>0.1 (0.2)</td>
<td>0.2 (0.6)</td>
<td>0.3 (1.0)</td>
<td>0.2 (0.9)</td>
<td>0.8 (2.4)</td>
</tr>
<tr>
<td>Maximum (SD)</td>
<td>12.7 (7.2)</td>
<td>15.7 (9.9)</td>
<td>17.8 (9.4)</td>
<td>18.9 (10.2)</td>
<td>17.2 (8.9)</td>
<td>16.9 (9.0)</td>
<td>16.2 (9.9)</td>
<td>29.2 (13.0)</td>
</tr>
<tr>
<td>Meal time, min</td>
<td>8.6 (5.5)</td>
<td>8.8 (5.4)</td>
<td>8.9 (4.5)</td>
<td>8.8 (5.0)</td>
<td>8.4 (5.1)</td>
<td>8.2 (4.9)</td>
<td>7.6 (4.9)</td>
<td>9.7 (5.0)</td>
</tr>
<tr>
<td>Minimum (SD)</td>
<td>0.4 (0.6)</td>
<td>0.8 (3.0)</td>
<td>0.3 (0.6)</td>
<td>0.2 (0.3)</td>
<td>0.4 (0.9)</td>
<td>0.6 (1.3)</td>
<td>0.5 (1.1)</td>
<td>0.8 (2.1)</td>
</tr>
<tr>
<td>Maximum (SD)</td>
<td>27.4 (18.8)</td>
<td>28.5 (17.0)</td>
<td>30.8 (18.6)</td>
<td>31.5 (18.6)</td>
<td>27.5 (18.2)</td>
<td>25.6 (14.7)</td>
<td>25.9 (17.8)</td>
<td>30.4 (14.4)</td>
</tr>
<tr>
<td>Inter-meal interval, h</td>
<td>2.9 (3.8)</td>
<td>3.3 (5.3)</td>
<td>2.4 (3.5)</td>
<td>2.1 (1.8)</td>
<td>3.0 (4.6)</td>
<td>2.2 (1.3)</td>
<td>3.5 (4.5)</td>
<td>2.0 (1.7)</td>
</tr>
<tr>
<td>Minimum (SD)</td>
<td>0.3 (0.7)</td>
<td>0.9 (4.1)</td>
<td>0.1 (0.2)</td>
<td>0.1 (0.1)</td>
<td>0.2 (0.1)</td>
<td>0.1 (0.1)</td>
<td>0.4 (1.1)</td>
<td>0.2 (0.9)</td>
</tr>
<tr>
<td>Maximum (SD)</td>
<td>8.7 (4.2)</td>
<td>9.0 (6.6)</td>
<td>9.0 (5.7)</td>
<td>9.4 (5.6)</td>
<td>9.1 (5.3)</td>
<td>9.8 (5.9)</td>
<td>11.2 (5.4)</td>
<td>9.3 (4.1)</td>
</tr>
<tr>
<td>Frequency of meals</td>
<td>9.7 (4.9)</td>
<td>10.6 (5.5)</td>
<td>12.5 (5.1)</td>
<td>12.1 (5.8)</td>
<td>11.5 (5.8)</td>
<td>11.5 (4.9)</td>
<td>10.4 (5.0)</td>
<td>12.3 (4.8)</td>
</tr>
</tbody>
</table>

1Feeding event with an interruption <300 s.
at 4 d before visual detection of BRD, the shortest meal was a significant predictor for BRD if only time variables were considered. The hazard for BRD decreased by 54% (SEM 17%) with an increase of 1 min in the shortest meal \((P = 0.04)\) if the remaining variables stayed constant. Moreover, the hazard for BRD decreased between 13% (SEM 3%) and 17% (SEM 3%) for every 1-min increase in feeding time per meal. Frequency increase by 1 meal per day resulted in a hazard decrease between 16% (SEM 2%) and 21% (SEM 2%). A 1-h increase in the mean time between 2 events significantly decreased BRD hazard (between 56% on day -5 and 21% on day -1; Table 3).

The BRD hazard model based on time variables predicted BRD in 81% of the cases 3 d before visual identification and 77% of the visually healthy steers were classified healthy using feeding behavior. Conversely, 4, 6, and 7 d before visual detection, less than 72% of the cases were identified by time variables and more than 77 (d 4) up to 84% (d 7) of the healthy population was classified healthy using feeding-time variables (Fig. 4).

**DISCUSSION**

The present study identified a decrease in the BRD hazard with an increase in mean feed intake per meal, mean meal time, and frequency of meals per day as early as 1 wk before visual identification, with highest prediction between 5 and 1 d before visual detection. Mean feed intake per meal appeared to be a useful tool for identifying susceptible cattle in the early stages of BRD. The BRD hazard decreased by at least 22%, with a 100-g increase of intake per meal throughout the week before pulling. In addition, steers with longer mean meals had lower hazards for visual BRD during the following week. Other feedlot studies compared total feeding time per day and frequency per day between sick and healthy animals in relation to DOF. Interestingly, they reported that frequency and total feeding time were lower between d 11 and 27 but greater between d 28 and 57 in sick cattle after arrival, which were attributed to post-sickness compensation (Buhman et al., 2000). Additionally, the Cumulative Sum Chart using cumulative presence and absence at the feedbunk identified 90% of the apparently sick feedlot cattle 4-d earlier in the disease process (Quimby et al., 2001). In other studies, accuracy of predictive models was highest from 1 to 7 d before pulling (Silasi, 2007). Similar to feedlot cattle, in dairy cattle, daily feed intake, feeding time, and frequency predicted metritis and other noninfectious diseases. Furthermore, cows with lower intakes, frequency, and shorter daily feeding time were readily identified as being high-risk for disease (Huzzey et al., 2007; Gonzalez et al., 2008a; Jawor et al., 2012). The advantage of the current study compared to previous studies was the ability to compare specific feeding behavior traits between sick and healthy steers in relation to the day of visual identification (in a group of cattle that was assembled over 24 h). Furthermore, in the present study, a specific case definition was used rather than relying only on visual appraisal. The current study additionally explored intake variables, which to our knowledge have not yet been described in relation to BRD identification. A recent review, however, argued that anorexia observed in ill animals is part of a coordinated strategy to fight disease. According to this theory, animals would rest more and decrease feeding and reproductive activities to preserve energy (Weary et al., 2009). This theory is further supported

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**Table 2.** Complete and differential blood cell count and acute phase proteins at first pull and percentage of steers greater or lower than the reference interval (RI) for haptoglobin-positive cattle with a rectal temperature \(\geq 40.0^\circ\text{C}\) and \(\geq 2\) clinical signs of bovine respiratory disease (BRD; \(n = 66\))

<table>
<thead>
<tr>
<th>Item</th>
<th>Median</th>
<th>IQR</th>
<th>RI</th>
<th>% outside RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>White blood cell count, 10^9/L</td>
<td>10.0</td>
<td>8.6 to 12.3</td>
<td>4 to 11</td>
<td>51.8</td>
</tr>
<tr>
<td>Neutrophils, 10^9/L</td>
<td>4.1</td>
<td>2.6 to 5.7</td>
<td>0.6 to 4.0</td>
<td>51.8</td>
</tr>
<tr>
<td>Lymphocytes, 10^9/L</td>
<td>5.7</td>
<td>5.1 to 6.9</td>
<td>2.5 to 7.5</td>
<td>19.6</td>
</tr>
<tr>
<td>Monocytes, 10^9/L</td>
<td>0.2</td>
<td>0.1 to 0.3</td>
<td>0.0 to 0.8</td>
<td>0</td>
</tr>
<tr>
<td>Eosinophils, 10^9/L</td>
<td>0.1</td>
<td>0.0 to 0.2</td>
<td>0 to 2.4</td>
<td>0</td>
</tr>
<tr>
<td>Basophils, 10^9/L</td>
<td>0.1</td>
<td>0.0 to 0.1</td>
<td>0 to 0.2</td>
<td>0</td>
</tr>
<tr>
<td>Red blood cell count, 10^12/L</td>
<td>10.1</td>
<td>9.4 to 10.8</td>
<td>6 to 9</td>
<td>83.9</td>
</tr>
<tr>
<td>Haemoglobin, g/L</td>
<td>130</td>
<td>122.5 to 134.5</td>
<td>100 to 150</td>
<td>3.6</td>
</tr>
<tr>
<td>Hematocrit, %</td>
<td>37</td>
<td>34 to 38</td>
<td>30 to 46</td>
<td>1.8</td>
</tr>
<tr>
<td>Total protein, g/L</td>
<td>69</td>
<td>67 to 75</td>
<td>67 to 75</td>
<td>8.8</td>
</tr>
<tr>
<td>Fibrinogen, g/L</td>
<td>5.7</td>
<td>4.5 to 7.3</td>
<td>3 to 7</td>
<td>30.4</td>
</tr>
<tr>
<td>Haptoglobin, mg/mL</td>
<td>2.6</td>
<td>1.4 to 2.4</td>
<td>0 to 0.15</td>
<td>n/a(^1)</td>
</tr>
<tr>
<td>Serum amyloid A, g/mL</td>
<td>127.2</td>
<td>85.8 to 143.7</td>
<td>0 to 80.3</td>
<td>75.4</td>
</tr>
</tbody>
</table>

\(^1\)IQR = interquartile range.  
\(^2\)RI = reference interval.  
\(^3\)n/a = not applicable.
by experimentally induced endotoxemia, which provided evidence that appetite in humans decreased with mounting immune response (Pollmächer et al., 2002).

Control steers fed on average 9.7 min per meal, with a frequency of approximately 12 meals per day, whereas BRD case steers fed on average between 7.6 and 8.9 min, with a frequency of 9.7 (d−7) to 12.5 (d−5) per day. Feed intake for the non-pulled cattle population was on average 1 kg per meal and pulled steers fed 0.4 and 0.5 kg per meal during the 7 d before pulling. Similar times and intakes have been reported for healthy cattle (Basarab et al., 2003; Schwartzkopf-Genswein et al., 2011). However, a restricted number of feeding places (32/213 steers) as opposed to open feedbunks with unrestricted access could have reduced dry matter intake (González et al., 2008b). Although limited bunk space for feedlot cattle is common (Alberta Agriculture and Rural Development, 2000), this effect needs to be further investigated, specifically in feedlot cattle experiencing health problems.

Fifty-seven percent of the visually identified and treated steers were classified as true BRD cases. This percentage was achieved by serial evaluation of the health status of pulled steers. The first step after visual identification and verification of fever (≥40°C) was serum testing using HP, a highly specific marker of inflammation, which has been previously described in a field study to successfully identify calves with BRD and to differentiate healthy from recovered cattle (Humblet et al., 2004). An additional factor for the case definition was the number of clinical signs of BRD. The clinical signs included in the disease definition are regularly used by pen checkers to identify cattle in need of further evaluation. In this study, steers with high rectal temperature more frequently displayed multiple signs of sickness compared to those with normal rectal temperature. Visual appraisal has low specificity and high variability among observers, depending on experience (Amrine et al., 2013). However, specificity of diagnostics can be increased if additional measures of disease status are included through serial testing (Dohoo et al., 2009). Although a widely accepted reference standard for BRD has not been described (Schaefer et al., 2012), it is essential to have a sound case definition when new technology is being tested or validated.

The high number of steers with elevated HP values (94%) as opposed to the relatively low numbers of steers above the cutoff for other blood end points resulted in inclusion of HP in the disease definition. The value of HP as a useful clinical parameter to measure the inflammatory response in cattle with BRD has been supported in numerous publications (Godson et al., 1996; Heegaard et al., 2000; Humblet et al., 2004; Orro et al., 2011). The cutoff for HP (0.15 mg/mL) used to define sick steers in the present study has been reported (Buhman et al., 2000) and lies within the range of other publications (Godson et al., 1996; Heegaard et al., 2000; Humblet et al., 2004). Furthermore, the current study

### Table 3. Hazard ratios for variables included in the final models to predict visual identification of bovine respiratory disease (BRD) in the first 35 d after arrival to the feedlot, with (Y) and without (N) feed intake measures; modeled between 1 and 7 d before visual identification (d−1 to d−7). The analyses included polynomial models of days on feed

<table>
<thead>
<tr>
<th>Days on feed</th>
<th>d−7</th>
<th>d−6</th>
<th>d−5</th>
<th>d−4</th>
<th>d−3</th>
<th>d−2</th>
<th>d−1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-meal interval, h</td>
<td>0.68</td>
<td>0.79</td>
<td>0.85</td>
<td>0.44</td>
<td>0.58</td>
<td>0.60</td>
<td>0.70</td>
</tr>
<tr>
<td>Meal time, min</td>
<td>0.87</td>
<td>0.86</td>
<td>0.87</td>
<td>0.89</td>
<td>0.86</td>
<td>0.85</td>
<td>NS</td>
</tr>
<tr>
<td>Shortest meal, min</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Frequency, N/d</td>
<td>0.79</td>
<td>0.86</td>
<td>0.80</td>
<td>0.86</td>
<td>0.84</td>
<td>0.89</td>
<td>0.81</td>
</tr>
<tr>
<td>Intake, 100g/meal</td>
<td>n/a²</td>
<td>0.71</td>
<td>n/a</td>
<td>0.72</td>
<td>n/a</td>
<td>0.74</td>
<td>n/a</td>
</tr>
<tr>
<td>Smallest meal, g</td>
<td>n/a</td>
<td>NS</td>
<td>n/a</td>
<td>NS</td>
<td>n/a</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Days on feed</th>
<th>Linear</th>
<th>Quadratic</th>
<th>Cubic</th>
<th>4th order</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC³</td>
<td>352</td>
<td>321</td>
<td>410</td>
<td>377</td>
</tr>
<tr>
<td>BIC⁴</td>
<td>393</td>
<td>363</td>
<td>451</td>
<td>419</td>
</tr>
</tbody>
</table>

1 NS = not significant (P > 0.05), not included in the final model.
2 n/a = not applicable.
3 AIC = Akaike Information Criterion.
4 BIC = Bayesian Information Criterion.
concorded with the findings in previous publications that white blood cell count may not be a good parameter to confirm inflammation due to pneumonia (Nikunen et al., 2007; Richeson et al., 2013). In agreement with previous publications, red blood cell count was greater than the reference value in the majority of pulsed steers (Fraser et al., 2014), with a low effect on the hematocrit. The high red blood cell count but normal hematocrit in BRD-affected cattle should be further investigated.

The treatment rate in the present study was high at 65% and most steers were treated early after arrival. This exceptionally high treatment rate was attributed to a sudden temperature drop and snowstorm in the first 10 DOF. Weather during the first 45 d after arrival was reported to be a significant risk factor for BRD in commercial feedlots (Cernicchiaro et al., 2012). Additionally, the induction protocol was treatment with long-acting oxytetracycline instead of the commonly used tulathromycin as a metaphylactic treatment. Based on a recent meta-analysis, oxytetracycline has low efficacy for treatment of BRD compared to tulathromycin, which will also explain the high treatment rate (O’Connor et al., 2013).

The present study could contribute to the development of algorithms to prospectively identify BRD in feedlots. Early treatment decreases negative effects of sickness and increases treatment efficacy (Ferran et al., 2011). Feeding behavior observations can and should be assessed for other economically important diseases besides BRD in feedlots. In that regard, the current study provided the basis for comparisons between clinically ill and visually healthy feedlot cattle. Future research should evaluate the economic value of early disease identification in feedlots.

A weakness of the current study was the missing clinical evaluation and blood sampling of steers not affected by clinical sickness. The researchers decided not to disturb the feedlot routine because pulling and examining healthy animals would be expected to have altered their feeding behavior, growth performance, and potentially health status. It is likely that this missing information led to an underestimate of the true difference in feeding behavior between healthy and sick cattle. Additionally, the environmental conditions were specific for the northern area of cattle feeding in the United States and Canada (AB). The study should be repeated under different environmental conditions to ensure generalizability of the results.

In conclusion, mean intake per meal as well as mean meal time and frequency of meals had merit to predict the hazard of BRD in feedlot cattle 7 d before visual detection and could be used to develop predictive algorithms for commercial application in feedlot settings.

**LITERATURE CITED**


