

Comparison of a Remote Early Disease Identification (REDI) System to Visual Observations to Identify Cattle with Bovine Respiratory Diseases

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KEY WORDS: Cattle, Bovine respiratory disease, disease detection, behavior

ABSTRACT

Background

Bovine respiratory disease (BRD) is the most common disease in the beef industry, and diagnosis based on visual observation of clinical signs is challenging. Cattle may alter behavior when diseased and technology exists to remotely monitor these behavioral changes. The objective of this study was a preliminary assessment of the ability of a remote early disease identification system (REDI) to identify cases of BRD compared to a trained observer.

Methods

Eighty cross breed bull calves (239 ± 19 kg) were used to evaluate potential differences in the two BRD diagnosis modalities. Bulls were randomly assigned to one diagnostic modality, and were then treated for respiratory disease only when that modality called them sick and their rectal temperature was above 40° C. Agreement and accuracy

between the two diagnostic modalities were compared.

Results

Within each treatment group, the numbers of pulls were nearly identical (REDI $n = 17/40$, visual observer $n = 16/40$), and the average days to first treatment were also similar. Both systems agreed on 83% of all daily individual observations, and this agreement is deemed as fair when evaluated using a kappa statistic on both a calf ($\kappa = 0.26$) and individual observation level ($\kappa = 0.23$). When using agreement of both systems and the temperature threshold to estimate true calf health status, there were no statistical differences between the two modalities and both REDI and visual observer methods illustrated a high probability of making the correct disease call, $94\% \pm 1.4$ and $92\% \pm 1.8$ respectively. This research tested the initial iteration of the system and further refinements to REDI algorithms evaluated post-hoc improved agreement to ($\kappa = 0.30$), and these algorithms would have identified sick cattle an average of 0.75 days before

the visual observer.

Conclusions

The initial assessment illustrates the REDI is a promising method to identify bovine respiratory disease with relatively high agreement to visual observation. The concept of remote observations identifying behavioral changes associated with disease appears to be valid and further research can evaluate system improvements and performance in broader populations.

BACKGROUND

Bovine respiratory disease (BRD) is the most common and expensive disease in the beef industry¹⁻². Cattle suffering from BRD are frequently identified based on clinical signs of illness and treated when their rectal temperature is above a pre-defined threshold³. Clinical signs of respiratory disease include depression, lack of appetite, increased respiratory rate, and increased nasal discharge. However, none of these signs are pathognomonic for BRD, and are often mistaken for other pathologic processes.

Previous studies have demonstrated low diagnostic accuracy of using clinical signs of illness in relation to lung lesions at necropsy.⁴ Therefore, more objective methods of identifying cattle suffering from BRD are needed. Several researchers have evaluated differences between healthy and morbid cattle with respect to time spent at locations of interest, daily activity, and the amount of time spent lying or standing,⁵⁻⁷ and have identified important differences between healthy and morbid cattle. The objective of our study was to conduct a blinded, randomized, controlled clinical trial to compare two BRD diagnostic methods: a novel remote early disease identification system (REDI) and a trained visual observer. A naturally occurring disease model (purchase of high risk calves) was used to evaluate efficacy of BRD identification based on different diagnostic modalities.

MATERIALS AND METHODS

All study procedures were conducted in accordance with a protocol approved by the

Professional Beef Services, LLC Institutional Animal Care and Use Committee.

Eighty high-risk cross breed bull calves (239 ± 19 kg) were purchased in a cohort (truckload) and arrived at the facilities in eastern MO, USA, in late January 2013. Upon arrival, all calves received a new identification ear tag (Allflex USA, INC, Dallas Fort Worth, TX), a REDI tag (PLUS Location Systems, Huntsville, AL), a clostridial (Vision 7, Merck Animal Health, Summit, NJ), and respiratory (Vista 5, Merck Animal Health, Summit, NJ) vaccination. Individual cattle were randomly assigned to one of two treatment groups, REDI (RD) or Visual Observation (VO) using a random number generator (Microsoft Excel, Redmond, WA). Cattle did not receive any other preventative health measures (metaphylaxis), and were started on long stem grass hay prior to transitioning to a standard ration consisting of wet corn gluten, soy hulls, and ground hay. Water was available ad libitum.

The REDI system consists of architecture (hardware and software) that provides real time positional information of each calf within the pen. The hardware consists of an ultra wide band tag transmitter attached to each calf via an ear tag and readers positioned around the pen that receive tag positional information and relay back to a central server. Patent pending algorithms evaluate positional information of each calf and determine health status based upon several locational, social, and behavioral indices. In the current trial, the REDI system provided a health status report classifying each animal as diseased or not once daily.

All cattle in both treatment groups were observed with both the REDI system and visual observation allowing a comparison of agreement between the two systems. A single trained veterinarian performed all visual observations, and was blinded regarding treatment group assignment, temperatures of cattle called ill, and which cattle were treated according to his determination of the disease state. As the REDI system required 3 days of baseline data before making a

Table 1. Health outcomes for cattle identified and treated based on the Remote Early Disease Identification (RD, n = 40) and the visual observer (VO, n = 40). The first time the calf was removed from the pen and above the rectal temperature cutoff, and thus received treatment, was the first treatment (Pull_1). If the calf was treated initially, then re-pulled and met the temperature cutoff, this was the second treatment (Pull_2).

	Treatment Group	
	RD (n = 40)	VO (n = 40)
Initial respiratory observe		
#	3	5
%	8%	13%
# received Pull_1	2	1
Initial treatment for BRD		
#	17	16
%	43%	40%
Average Days on feed	7.9	7.6
Average rectal temperature	105.7	105.5
Respiratory observes after 1st treatment		
#	5	4
# received Pull_2	3	1
Second treatment		
Pull_2	5	3
Pull_2 %	13%	8%

disease call, the visual observer made all disease determinations for all cattle for the first 3 days after arrival. Any cattle found ill during the initial 3-day period were removed from the study population and data analysis.

Following that initial 3-day period, cattle in the VO group were managed according to conventional industry practices with visual observations occurring once daily and all treatment decisions based on calves the observer visually observed for BRD with elevated rectal temperature ($> 40^{\circ}\text{C}$). Cattle in the RD group were monitored and treatment decisions based on the daily call of their health status using the pre-established REDI disease detection algorithms. Cattle in the RD group identified as diseased by the REDI system were taken to the chute and eligible to be treated if rectal temperature was elevated ($> 40^{\circ}\text{C}$).

All rectal temperatures were recorded

and treatments administered by a third party (not the veterinarian making the disease call) facilitating the blinding of the visual observer. Thus, cattle in the VO group were only treated based on the trained visual observers decision, while cattle in the RD group were only treated based on the computer classification. The therapeutic protocol for the first time an animal met the BRD case definition was an antimicrobial, florfenicol (Nufloor, Merck Animal Health, Summit, NJ). Cattle were not eligible for retreatment for 72 hours past the initial treatment; if they were deemed sick, they were not evaluated during this post-treatment moratorium. If cattle were identified as ill after this interval, they were treated with tildipirosin (Zuprevo, Merck Animal Health, Summit, NJ) and were not eligible for treatment for an additional 7 days after this injection. An individual weight was recorded on all cattle

Table 2. Agreement of BRD diagnosis among calves identified by remote early disease identification (RD group) or visual observation (VO). Calves within each methodology group were only eligible for treatment if identified as positive for BRD by that diagnostic modality.

2a. Calves in RD group (n = 40)

Treated for BRD			Not treated for BRD		
	RD +	RD -		RD+	RD-
VO +	13	0	VO +	0	9
VO -	4	0	VO -	1	13

2b. Calves in VO group (n = 40).

Treated for BRD			Not treated for BRD		
	RD +	RD -		RD+	RD-
VO +	5	11	VO +	0	3
VO -	0	0	VO -	2	19

at the time of treatment administration.

Cattle in the RD group were only removed from the pen for evaluation when the REDI system called them sick, while cattle in the VO pen were only removed for evaluation when the observer called them sick. If a calf was removed from the pen prior to any treatment and temperature was $< 40^{\circ} \text{C}$, this was called a respiratory observe prior to first treatment (RO_preTx1). The first time the calf was removed from the pen and above the rectal temperature cutoff, and thus received treatment was considered the first treatment (Pull_1). After initial treatment, if a calf was removed from the pen (after the post-treatment moratorium), but did not meet the rectal temperature cutoff, this was considered a respiratory observe after the first treatment (RO_postTx1). If the calf was treated initially, then re-pulled and met the temperature cutoff, this was considered the second treatment (Pull_2).

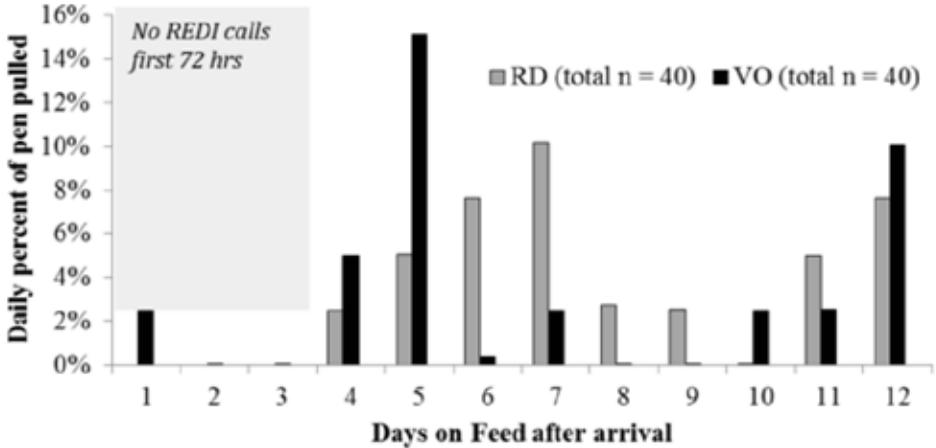
The trial was scheduled to last 45 days; however, due to a severe disease outbreak, a mass treatment of the entire pen (both treatment groups) was instituted 13 days after study initiation and comparisons between the two disease detection systems (VO and REDI) are limited to these initial 13 days. Mass treatment was initiated as this would have been standard practice with the level of morbidity (both the observer and REDI

system identified nearly 20% of the pen as diseased).

STATISTICAL ANALYSIS

All data were imported into statistical software (JMP, Version 10, SAS Institute Inc., Cary, NC) for descriptive and statistical analysis. Agreement between the systems on each calf was evaluated by comparing the daily disease call of each animal and Kappa statistics (κ) were generated to determine areas of strong or weak agreement. Standard health (first treatment success rate and case fatality rate) and performance outcomes (overall group ADG, and ADG of treated cattle) were measured and compared between disease detection groups. A BRD determination was deemed as being correct if both systems agreed (that the calf was healthy or ill), or if the calf was identified as ill by the system used for that calf's treatment group and determined to be above the temperature threshold. If either VO or REDI called a calf sick, but that calf was in the other treatment group, a temperature was not taken. Thus the true status was considered unknown and these data were removed from the analysis on the probability of each system making a correct determination of health status. A call was deemed incorrect if one system called the calf ill (meeting temperature cutoff) and the other did not, or if

Figure 1. Distribution of the first treatment by days on feed after arrival. Cattle identified using the Remote Early Disease Identification system (RD) compared to the Visual observation (VO).



one system called the calf ill (but it did not meet the temperature cutoff) and the other did not. Logistic regression was used to estimate the likelihood of a correct call by each system and included random effects for individual calves and days to account for the hierarchical structure of the data.

RESULTS AND DISCUSSION

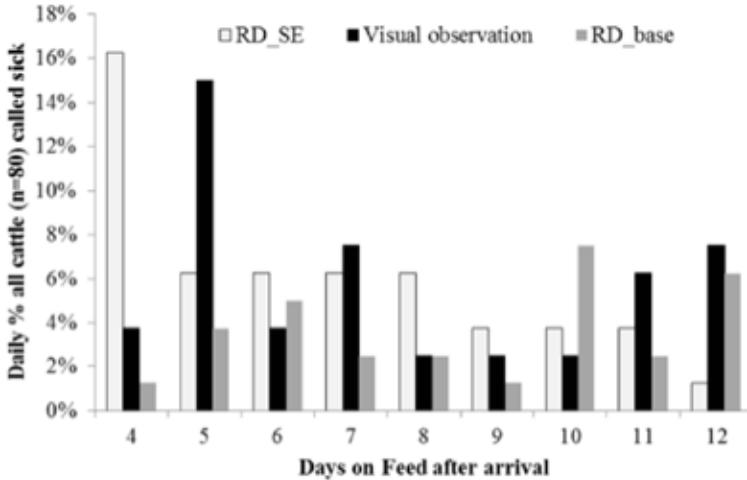
Eighty bull calves (239 kg ± 19 kg) arrived at the research facility on January 24, 2013, and were processed and placed in a single pen. The VO group (n = 40) had an average arrival weight (± standard deviation) of 232.8 ± 16.9 kg, while the RD group (n = 40) averaged 243.5 ± 19.7 kg. The trial was scheduled to last 45 days. However, due to a severe disease outbreak primary investigators initiated a mass treatment of the entire pen on 13 days after cattle arrival. The mass treatment was initiated as this would have been standard practice with the level of morbidity (both the observer and the REDI system identified nearly 20% of the pen as diseased on study day 12). The trial was abbreviated; however, data until the trial conclusion on day 13 (February 6th) can still be evaluated.

Both the RD and VO cattle had similar initial respiratory observes (RO_preTx1) prior to first treatment, and initial pull rates based on the respective disease calls within

each treatment group (Table 1). However, of the calves the REDI system identified as initial respiratory observes (an observation that resulted in taking a temperature that was less than 40° C), two of these three calves eventually met the BRD case definition and temperature threshold, and were treated. In the VO calves, there were five respiratory observes prior to the initial treatment, but only one of those calves was eventually treated. The same trend held after the initial treatment, as respiratory observes after initial pull for the REDI system resulted in three of these five calves being treated a second time (Pull_2), while only one of four in the VO pen that had a respiratory observe after the initial treatment was eventually considered a repull.

In aggregate, there were eight times a calf was identified as ill by the REDI system but did not meet the temperature cutoff, and five of those calves were eventually treated. There were nine times the visual observer identified calves as clinically ill and they did not meet the temperature cutoff, and only two of those calves were eventually treated. Previous research has estimated using clinical signs of illness in combination with temperature to have low diagnostic sensitivity (61.8 %) and specificity (62.8%),⁸ and while the current trial is not conclusive evidence,

Figure 2. Distribution of all cattle (n=80) called sick by day after arrival using three different methods of classification: visual observation (VO), the baseline RD algorithm (RD_base), and a more sensitive RD algorithm (RD_SE). Days 1-3 cattle were not eligible to be called sick by Remote Early Disease Identification (RD_SE or RD_base) system.



it does provide some information that the REDI system may be more specific than a visual observer based on clinical signs when temperature and eventual treatments are used to judge outcomes.

The calves were managed in the same pen and wellness state determined by both the VO and RD each day for each calf. Only calves deemed ill by VO in the VO group had rectal temperatures measured, and the same was true for the RD calves. The two systems were compared by evaluating the agreement on individual calves each day. On a calf level, the two systems agreed on 18 sick calves and 32 healthy calves at every measurement during the trial resulting in $\kappa = 0.26$, representing fair agreement.⁹ A full breakdown of the number of calves based on calls within each treatment group is represented in Table 2.

Of the seven calves that RD called sick, but VO did not, five were in the RD group and four of these five were treated. The RD system called these four calves sick an average of 4.3 times, but VO never identified as diseased. Of the 23 calves VO called sick, but RD did not, only 14 were in the

VO group and 11 of 14 were treated. The VO system called these 11 calves sick an average of 1.6 times, but RD never called them ill. Comparing the discrepancies among systems revealed that in cases where RD determined animals were sick and VO did not, RD called the calves sick multiple times, but when the converse situation was true,

VO typically only called them diseased a single time, potentially representing a false positive diagnosis.

In the VO group, 7 of these 11 calves were only called clinically ill one time, and as the observer was blinded to treatment group and treatment administration, these cases likely represented a transient illness or fever (as they were only called sick a single time, and not called sick on consecutive days). Ideally, the next trial will allow longer term comparisons of performance, and health outcomes for calves that were identified and treated using one system, but not identified with the other system.

The disease calls on all 80 calves for every day of the trial past the post-arrival evaluation period (9 days total) resulted in 720 observations for comparison. The comparison of daily disease determinations resulted in 28 calf days where both systems called the calves sick, and 575 calf days where both systems called the calves healthy meaning, that they agreed on 83.7% of the calf days for an overall $\kappa = 0.23$ (fair agreement). However, agreement on a calf or

daily basis does not provide a full evaluation of the system, as neither system is perfect in classifying the true status of the animals. Previous studies evaluating alternative methods of identifying sick calves were also found to be less than perfect.⁷

An important consideration is the timing of each system with regard to identifying sick animals. The average days on feed at first treatment was similar for the VO group (7.6 d) relative to the RD group (7.9 d), and the timing of pulls is further illustrated by plotting the percentage of each group treated by day (Figure 1). Of calves called sick by both algorithms and treated, half of them (9/18) were called sick by both systems on the same day or within 1 day. Of the remaining calves, RD called two sick prior to VO (average 4.5 d before), and VO called seven sick before RD (average 4.4 d before). Our hypothesis was that the RD system would call animals sick prior to VO; however, that did not consistently occur in this trial.

The accuracy of both systems is difficult to determine, as there is no gold standard for BRD status. However, the trial used a rectal temperature cutoff (40° C) to make the final treatment decisions. There were approximately 10% of all calls where the accuracy could not be determined due to disagreement between the systems (and not measuring rectal temperature because a calf determined ill by one system was not evaluated for temperature if present in the other treatment group), but only approximately 1% occurred on any given day. As both systems were blinded to actual treatment status, many of these disagreements resulted from the post-treatment moratorium (3 days) after a calf was treated, but ineligible for retreatment (thus rectal temperature not evaluated). Of the 77 calf days where disagreement was determined, but no temperature was taken, two were the result of missing data from the REDI system due to tag changes on the previous day, 46 were times VO called the calf positive and RD called the calf negative, and 29 were instances RD called the calf positive and VO

called the calf negative. These exclusions likely bias the results toward higher overall accuracy, but as they are nearly equal among treatment groups, it is unlikely they modify the relationship between VO and RD.

The likelihood of a correct call was analyzed using logistic regression to evaluate potential differences due to day or repeated measures on individual calves. There was no interaction between trial day and system when evaluating correct call. There was no difference ($P = 0.34$) in the probability of correct calls between VO ($92\% \pm 1.8$) and RD ($94\% \pm 1.4$). Both systems were more likely to make a correct call when the true status of the animal was determined to be healthy ($98\% \pm 0.4$) compared to when BRD positive ($81\% \pm 4.4$). The analyses show very good accuracy by both systems. A flaw in this analysis is the ignoring of calves that were called ill by one system, but since they were in the other treatment group, the rectal temperature was not determined. This could be modified in subsequent trials by taking temperatures on all calves deemed sick by either system, regardless of treatment group. Overall, this illustrates a high level of accuracy for both the VO and RD, but results are only compared to each other using temperature as the true disease state of each calf is unknown.

The REDI system has multiple disease detection algorithms that can be employed depending on the circumstances and goals of the observations. Some algorithms are more sensitive and others more specific, and an algorithm optimized for both sensitivity and specificity was used for this trial. A more sensitive algorithm was used to evaluate data after the trial and the calf level Kappa improved to 0.30, but potentially more importantly, the RD system would have identified calves on average of 0.75 d earlier than VO (Figure 2). The more sensitive algorithm identified a large number of sick calves early (d 4), and this may have modified the population outcome. The impact of treating a majority of the diseased calves on day 4 (as suggested by the more sensitive algorithm)

on the overall pen dynamics and the scope of the outbreak is unknown, but potentially this could be a valuable tool in larger disease outbreaks.

CONCLUSIONS

This research illustrates the ability of the remote early disease identification (REDI) system to identify calves with BRD relative to the traditional method of visual observation. In this trial, the calves faced severe disease. However, the system showed fair agreement with visual observation and illustrated very good accuracy in cases with known outcomes. The results illustrate the concept of remote measurement of behavior and identification of changes in wellness status is possible, and further improvements could be made by utilizing multiple algorithms which would allow for earlier identification of disease. Further research needs to be performed to develop the final value of the system; however, the initial results from this trial are very promising.

COMPETING INTERESTS

This research was partially funded by Merck Animal Health and Professional Beef Services, LLC. PBS holds the intellectual property patents on the Remote Early Disease Identification (REDI) system algorithms.

AUTHORS' CONTRIBUTIONS

BW is the corresponding author; BW and DG designed and conducted the study; and DA wrote the primary draft of the manuscript. All authors have contributed to, read, and approved the final manuscript.

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