Associations between feeding behaviors collected from an automated milk feeder and disease in group-housed dairy calves in Ontario: A cross-sectional study

M. H. Conboy,¹ C. B. Winder,¹ C. Medrano-Galarza,^{1,2} S. J. LeBlanc,¹ D. B. Haley,¹ J. H. C. Costa,³ M. A. Steele,⁴ and D. L. Renaud^{1*}

¹Department of Population Medicine, University of Guelph, Guelph, ON, Canada, N1G 2W1

²Programa de Especialización en Bienestar Animal y Etología, Facultad de Medicina Veterinaria, Fundación Universitaria Agraria de Colombia, Bogotá, Colombia, CII170#54a-10

³Department of Animal and Food Sciences, University of Kentucky, Lexington 40508

⁴Department of Animal Biosciences, University of Guelph, Guelph, Ontario, Canada N1G 2W1

ABSTRACT

The adoption of automated milk feeders and group housing of preweaning dairy calves has become more common in Canada; however, disease detection in group-housed calves remains a challenge. The aim of this cross-sectional study was to assess whether feeding behavior data collected from a single point in time could be used to aid in the detection of neonatal calf diarrhea (NCD), bovine respiratory disease (BRD), and general disease, in preweaning group-housed calves being fed via an automated milk feeder. The data used was collected in an earlier study. A total of 8 dairy farms recruited from an online survey of calf-management practices were enrolled into the study. There was a total of 523 observations with 130 events of NCD, 115 events of BRD, and 210 events of general disease. Each farm was visited once in each of the fall, winter, spring, and summer, when the calves' health was scored, and the data were collected from the automated milk feeders. Mixed linear regression models were used to identify associations between feeding behavior data (milk consumption, time spent at the feeder, drinking speed, and the number of rewarded and unrewarded visits) and the presence of NCD, BRD, or general disease (having one or more of NCD, BRD, or umbilical infection), on the day of health scoring. Generalized linear mixed models were used to analyze the percentage of milk the calf consumed from their daily milk allotment. Calves with BRD consumed 63% less of their daily allotment of milk, had 2 fewer unrewarded visits to the automated milk feeder, and drank milk 152 mL/min slower compared with calves without BRD. Calves with NCD consumed 57% less of their daily milk allotment,

consumed 758 mL less per day, and drank 92 mL/min slower than calves compared with calves without NCD. Calves with general disease drank 50% less of their daily milk allowance, consumed 496 mL less per day, drank 80 mL/min slower, and had 2 fewer unrewarded visits to the automated milk feeder, when compared with calves without disease. No significant associations were found between the presence of NCD, BRD, or general disease and time spent at the feeder or number of rewarded visits. Sensitivity and specificity values for disease identification were low when evaluating the feeding behaviors individually, so parallel testing was completed. To do so, if any significant feeding behavior was below the optimal cut point for disease detection as determined using a ROC curve, the calf was considered positive for disease and the sensitivity and specificity were recalculated. Parallel testing resulted in a sensitivity of 0.82, 0.78, and 0.84, and a specificity of 0.26, 0.23, and 0.21, for BRD, NCD, and general disease, respectively. This suggests that automated milk feeders may serve as a useful preliminary tool in the detection of diseased calves. For example, producers could use feeding behavior data to identify calves requiring further inspection; however, they should not use feeding behavior data as a sole disease detection method.

Key words: health, automation, group housing

INTRODUCTION

The adoption of automated milk feeders (AMF) in Canada has increased greatly, from no farms reporting use of an AMF in a survey conducted in Quebec between 2005 and 2007 (Vasseur et al., 2010) to 16% of farms using an AMF in a survey of Canadian producers in 2015 (Medrano-Galarza et al., 2017). The use of an AMF allows for calves to consume a higher quantity of milk through more feedings per day, leading to the expression of more natural feeding behaviors (Jensen

Received January 7, 2021.

Accepted April 22, 2021.

*Corresponding author: renaud@uoguelph.ca

and Weary, 2013; Medrano-Galarza et al., 2017). In addition, the AMF can improve labor conditions for farm workers by eliminating the need for preparing and feeding milk, especially in inclement weather conditions. This, along with improved animal welfare, were key reasons identified by producers for their switch to an AMF (Medrano-Galarza et al., 2018a).

The use of an AMF system typically requires group housing of calves, which can make it challenging for producers to monitor calves individually for the development of disease and was the main perceived disadvantage of AMF systems (Kung et al., 1997; Medrano-Galarza et al., 2018a). Increased disease transmission has also been associated with group housing as compared with individual housing; calves housed individually had a lower prevalence ($6 \pm 0.7\%$) of bovine respiratory disease (**BRD**) than calves housed in groups ($15 \pm 2\%$; Karle et al., 2019). Similarly, Svensson et al. (2003) found that the risk of BRD was greater in calves housed in groups of 6 to 30 calves compared with calves housed individually (14 vs. 5%, respectively); however, there were no differences in the risk of neonatal calf diarrhea (**NCD**).

Despite the challenges associated with group housing, an AMF offers additional benefits through the feeding behavior metrics collected for each individual calf (Costa et al., 2020). One of the initial behavioral changes in response to disease is loss of appetite (Dantzer, 2009), so the AMF may potentially be useful to detect disease using changes in the feeding behaviors that it measures. Common feeding behavior metrics measured by an AMF are total milk consumption (mL/d), percentage of the daily milk allotment consumed, total time spent at the feeder (min), drinking speed (mL/min), the number of rewarded visits (the calf receives milk), and the number of unrewarded visits (the calf does not receive milk because it has visited the feeder before the minimum meal interval set by the manager has passed (e.g., 2 h; Costa et al., 2020). Several studies have examined the changes of drinking behavior in the days before and after detection of illness. For calves fed, on average, 9.4 L of milk/d, a significant decrease in drinking speed was found on the day of diagnosis of BRD, and the number of unrewarded visits was reduced in the 10 d leading up to the diagnosis of disease (Knauer et al., 2017). Similarly, the number of unrewarded visits decreased 2 d before diagnosis of BRD in calves fed 6 L or 8 L of milk/d (Svensson and Jensen, 2007) and 2 d before the diagnosis of NCD in calves fed 6 L of milk/d (Sutherland et al., 2018). Diseased calves have also been shown to consume significantly less milk than healthy calves 4 to 7 d before diagnosis of disease (Knauer et al., 2017; Sutherland et al., 2018). However, other studies found

that diseased calves consumed significantly less milk than healthy calves only on the day of disease diagnosis (Borderas et al., 2009; Swartz et al., 2017).

To help producers detect disease quickly, without looking at daily fluctuations in feeding data, it could be useful to identify associations between single-day drinking behaviors and disease. The producer could then use that information to help identify which calves need to be examined or whether the calf should be treated if the calf is exhibiting nonspecific or mild symptoms. Therefore, the objectives of this study were to determine if the feeding behavior data on the same day as disease diagnosis was associated with BRD, NCD, or general disease [having one or more of BRD, NCD, or umbilical infection (**UI**)] at the calf level on dairy farms feeding milk via an AMF to group-housed calves. It was hypothesized that the feeding behaviors could be used to detect disease of calves at a single point in time with a high level of accuracy.

MATERIALS AND METHODS

This cross-sectional study was reviewed and approved by the University of Guelph Animal Care Committee (Animal Use Protocol #3212) and was reported using the STROBE Vet checklist for observational studies (von Elm et al., 2008).

Farm Enrollment and Farm Visits

The data used in this study was collected as part of a previous study completed by Medrano-Galarza et al. (2018b). Dairy farms that participated in an online survey on calf-management practices (Medrano-Galarza et al., 2017) were asked if they wanted to further participate in an on-farm study. Of these farms, those within a 2.5-h drive of Guelph, Ontario, were contacted by telephone to confirm participation and to schedule a farm visit. Of the 73 farms who wanted to participate in the research study, only 18 farms fulfilled the location requirements, and 17 of these agreed to participate. Of the 17 farms, 8 used a Förster Technik AMF, which saved daily feeding data, and these were the farms included in this study.

From the fall of 2015 to the summer of 2016, each farm was visited once a season, totaling 4 visits/farm. Fall visits occurred between November 2 and December 1, 2015; winter visits between February 3 and March 16, 2016; spring visits between April 19 and May 30, 2016; and summer visits between August 3 and September 6, 2016. All health measurements were performed by the same trained researcher on the day the AMF data were collected.

Calf Health Measurements

During each of the visits, the health of all calves housed in group pens with an AMF was classified using the fecal consistency and respiratory scoring system as developed and described by McGuirk (2008) and McGuirk and Peek (2014). Calves were scored on 4-point scales with 0 being normal and 3 being severely abnormal, as shown in the Calf Health Scorer (University of Wisconsin-Madison, 2021). A calf was classified as having BRD if the cumulative score for nasal discharge, ocular discharge, ear position, cough score, and rectal temperature was ≥ 5 . The calf was diagnosed as having NCD if the fecal score was 2 or 3. A calf was classified as diseased if it had at least one or more of BRD, NCD, or UI (score of 2 or 3). For calves with BRD and NCD, the comparator calves were defined as calves without BRD and NCD, respectively, whereas for general disease, the comparator calves were calves without BRD, NCD, or UI.

Using birth records provided by each farm, the age of the calf on the day of assessment was calculated. The date on which calves were started on the AMF was collected from the AMF directly and was used to calculate the age of the calf at introduction to the feeder and the number of days the calf was on the feeder, known as days on the AMF, on the day of assessment.

Drinking Behavior Measurements

Drinking behaviors [milk consumption (mL/d), drinking speed (mL/min), the number of rewarded visits, and the number of unrewarded visits] of the entire day were collected on the day of health scoring. These drinking behavior data were collected directly from the AMF at each visit by using the handheld terminal with an SD memory card. All of the AMF used were made by Förster Technik. The time of entry and exit times of each visit to the AMF was collected directly from the feeder. This was used to calculate the time at the AMF variable, which was the total time (min) that the calf spent per day in the AMF stall. In addition, information regarding the milk feeding plan was collected from the AMF, which included the volume of milk the calf consumed in mL and as a percentage of its daily milk allotment. All farms fed calves milk replacer, except for farm 7, which fed a combination of whole milk and milk replacer.

The data used here are a subset of data collected for another study (Medrano-Galarza et al., 2018b). Specifically, data were used from 8 of the 17 farms used in the previous study, as AMF data were not available for all the farms included in that study. The excluded farms

used feeders that were not able to save feeding behavior data and therefore, did not have the data available.

Statistical Analysis

The data collected were recorded in Microsoft Excel version 16.48 (Microsoft Corp.) and analyzed with Stata 15 (Stata Corp.). Calves older than 56 d were excluded to eliminate calves on restricted intakes during the weaning process.

Mixed linear regression models were used for analysis for all variables except milk allotment. Farm and season were included as random effects with season nested within farm for all mixed linear regression models. For milk allotment, a robust generalized linear model with a logit link and binomial family was used. Milk consumption (mL/d), milk allotment consumption (% consumed of total daily allowance), time spent at the AMF (min/d), drinking speed (mL/min), and number of rewarded and unrewarded visits were examined as outcomes. Predictor variables were whether or not the calf was diagnosed as having BRD, NCD, or general disease (0 = no, 1 = yes). Models were built for each of these predictor variables individually. Age of the calf at introduction to the AMF, days on the AMF, age of the calf, and the sex of the calf were also offered as covariates.

Correlation analysis was done for all continuous and categorical variables to assess for multicollinearity by determining the Spearman rank correlation value. Age and days on the AMF were highly correlated ($\rho = 0.9$). Therefore, only days on the AMF was considered for model building. The linearity assumption was assessed graphically and by testing a quadratic term for continuous variables. If the quadratic term was significant, the variable was modeled as a quadratic. If a continuous variable did not have a linear or quadratic relationship with the outcome variable, it categorized into tertials for age at introduction to the AMF (0–6, 7–10, and 11–37 d old) or quartiles for days on the AMF (0–12, 13–22, 23–35, and 36–56 d). Each predictor and covariate were initially assessed individually in each model. Variables were added to the multivariable model if in univariable analysis they had a $P < 0.20$. All biologically plausible interactions were tested and were kept in the model if $P < 0.05$. Confounding was assessed by determining the change in the coefficient of the outcome variable when the potential confounding variable was included and removed from the multivariable model. If the change was more than 25%, the variable was considered a confounder and was retained. The multivariable model was then reduced through backward stepwise elimination resulting in only variables with P

< 0.05 remaining in the model. Assumptions of normality and homoscedasticity of the residuals and the BLUP were assessed graphically. Residuals and BLUP were considered normal if the data points fell on a 45-degree line in a normal quantile plot and were considered homoscedastic if the data points fell between 2 constant bands. Outliers were examined graphically and through lists. Any outlier >3 or <-3 of the standardized residuals were examined by assessing its effects on the model if it was removed. The total number of outliers for the models evaluating milk consumption, total time at the AMF, drinking speed, the number of rewarded visits to the AMF, and the number of unrewarded visits to the AMF were 6, 2, 1, 7, and 9, respectively. However, removal of these outliers did not have a major effect, and all data were retained in the final models. Outliers were not evaluated for the milk allotment models, because they were accounted for in the robust regression. The intraclass correlation coefficient was calculated to describe the variance at the farm and season levels.

The optimal cut point optimizing the sensitivity and specificity of each feeding behavior in detecting disease was calculated using Youden's index. For each disease, parallel testing was completed using only the significant feeding behaviors from the final multivariable models. All these feeding behaviors were assessed at once and if any of the feeding behavior values were below the optimal cut point for disease detection, then the calf was considered positive for that disease. The sensitivity and specificity were then calculated using parallel testing.

RESULTS

A total of 523 calves were assessed at a single time point per calf, from the fall of 2015 to the summer of 2016. On the day of examination, the median age of the calves was 33 d [range: 2–56 d; interquartile range (IQR): 22–45 d], and the median days on the AMF was 22 d (range: 1–56 d; IQR: 13–36 d). The median age of calves at introduction to the feeder was 8 d (range: 0–37 d; IQR: 6–12 d) and the majority (71%) of calves were female.

Prevalence of Disease

Of the 523 calves assessed, 40% ($n = 210$) were classified as having general disease (identified as having one or more of BRD, NCD, or UI). Specifically, 25% ($n = 130$) had NCD, and 22% ($n = 115$) had BRD. Among calves with NCD, 30% ($n = 39$) also had BRD. The mean within-herd prevalence of general disease for all visits was 39% (range: 22–68%; IQR: 24–50%), whereas the mean within-herd prevalence of NCD and

BRD were 26% (range: 10–50%; IQR: 14–34%) and 19% (range: 7–35%; IQR: 13–24%), respectively. The mean age of calves with NCD was 25 d (range: 7–55 d; IQR: 16–33 d), whereas for calves with BRD it was 35 d (range: 12–56 d; IQR: 25–47 d). On average, calves were identified as having NCD at a median of 18 d (range: 1–45 d; IQR: 8–25 d) on the AMF, whereas calves classified as having BRD had been on the AMF for a median of 26 d (range: 1–50 d; IQR: 15–35 d). The majority of cases of general disease occurred in the spring (31%; $n = 65$) with the fewest cases occurring in the fall (14%; $n = 30$). Neonatal calf diarrhea occurred most frequently in winter (32%; $n = 42$), whereas BRD was most prevalent in the summer (31%; $n = 36$).

Daily Milk Consumption

The mean daily milk consumption of the calves was 6,970 mL (range: 1,300–15,000 mL; SD: 2,169 mL). The range of milk consumption and feeding plans for each individual farm, found in Table 1, varied greatly and resulted in some calves having limited milk intake if they had not been on the AMF for many days at the time of assessment. There were 521 calves included in the NCD model, 130 of which had NCD. In univariable analysis, days on the AMF and the presence of general disease and NCD were associated with milk consumption. For the multivariable model examining associations with NCD, calves that had NCD drank less (758 mL; 95% CI: 341–1,174; $P < 0.001$) than calves that did not, while accounting for days on the AMF (for every 1 d increase on the AMF: 126 mL; 95% CI: 79–172; $P < 0.001$) and the quadratic term for days on the AMF (for every 1 d increase on the AMF: 3 mL; 95% CI: 2–4; $P < 0.001$). There was no significant association between milk consumption and BRD. For the model examining associations with general disease (one or more of BRD, NCD or UI) there were 523 calves, 210 of which had general disease. Calves with a case of general disease drank less (496 mL; 95% CI: 129.6–862.3; $P < 0.001$) than healthy calves, accounting for days on the AMF (for every 1 d increase on the AMF: 128.2 mL; 95% CI: 130–862; $P < 0.001$) and the quadratic term for days on the AMF (for every 1 d increase on the AMF: 3 mL; 95% CI: 2 to 4; $P < 0.001$). There were no interactions or confounding variables identified in the models evaluating the volume of milk consumed. The interclass correlations for the models evaluating NCD and general disease were 0.08 and 0.09, respectively. Milk consumption had a sensitivity of 0.50, 0.55, and 0.59 in detecting BRD, NCD, and general disease, respectively, whereas it had a specificity of 0.44, 0.38, and 0.35 in detecting BRD, NCD, and general disease, respectively (Table 2).

Table 1. Feeding plan and actual milk consumption of each individual farm with group-housed preweaning dairy calves being fed via a Förestek Technik automated milk feeder¹

Farm	Season	Number of days			Milk consumption (L)			Actual milk consumption (mL)	
		Ramp-up phase	Hold phase	Ramp-down phase	Ramp-up phase	Hold phase	Ramp-down phase	Average	Range
1	All	NA ²	46	10	NA	9	9–2	6,765	1,500–9,000
2	Fall	14	29	20	3.5–6	6	6–2	6,157	2,000–8,000
	Spring	18	14	18	5–8	8	8–2		
	Winter	18	18	14	5–8	8	8–2		
	Summer	14	28	14	5–8	8	8–2		
3	All	28	NA	32	9–12	NA	12–2	8,286	2,500–15,000
4	All	46	NA	14	6–10	NA	10–5	7,891	5,000–9,937
5	Fall	9	33	18	6.5–9.5	9.5	9.5–2	6,547	3,178–9,281
	Remaining	6	NA	54	6.5–7.5	NA	7.5–1		
6	All	15	30	15	5–8	8	8–2	6,421	1,300–8,000
7	All	NA	28	28	N/A	11	11–2	7,495	2,224–12,500
8	Summer	21	28	14	5.5–9	9	9–1.5	7,723	1,422–11,007
	Remaining	21	28	14	5.5–10	10	10–1.5		

¹All farms fed calves milk replacer except for farm 7, where calves were fed a mixture of whole milk and milk replacer. The farms were located in southern Ontario, Canada, and visited once a season from fall 2015 to summer of 2016.

²NA = not applicable for this farm.

The mean daily percentage of milk allotment consumed was 91% (range: 16–100%; SD: 20%). The proportion of daily milk allotment consumed was associated with the presence of BRD, NCD, and general disease, as shown in Tables 3, 4 and 5, respectively. Calves classified as having BRD, NCD, and general disease drank a smaller proportion of their milk allotment (63, 57, and 50%, respectively) compared with calves without BRD, NCD, or general disease, respectively. The percentage of milk consumed by the calf of their total daily milk allotment had a sensitivity of 51% in detecting each disease and a specificity of 32, 31, and 27% in detecting BRD, NCD, and general disease, respectively (Table 2).

Drinking Speed

Calves had a mean drinking speed of 744 mL/min (range: 46–1,429 mL/min; SD: 274 mL/min). There was a total of 466 calves included in the BRD model, 103 of which had BRD. In the general disease model, 466 calves were included, 185 of which had general disease. There were 465 calves included in the NCD model with only 115 of the calves having NCD. Daily drinking speed was lower in calves that had BRD, NCD, or general disease. Calves with BRD, NCD, and general disease drank 152.6 mL (95% CI: –96.8 to –208.5; $P < 0.001$), 92.4 mL (95% CI: –34.2 to –150.7; $P < 0.002$) and 80.2 mL (95% CI: –46.3 to –114.2; $P < 0.002$) respectively.

Table 2. Diagnostic ability of feeding behaviors in detecting bovine respiratory disease (BRD), neonatal calf diarrhea (NCD), and general disease (one or more of BRD, NCD, or umbilical infection) in group-housed preweaning dairy calves being fed via a Förestek-Technik automated milk feeder¹

Disease	Predictive measurement	Total daily milk consumption (mL)	Milk allotment (%)	Drinking speed (mL/min)	Unrewarded visits	Parallel analysis
BRD	Optimal cut point	7,171	1.00	769	3	—
	Sensitivity	0.50	0.51	0.37	0.35	0.82
	Specificity	0.44	0.32	0.54	0.40	0.26
	Area under ROC ² curve at cut point	0.47	0.41	0.45	0.38	0.54
NCD	Optimal Cut point	6,782	1.00	741	2	—
	Sensitivity	0.55	0.51	0.41	0.42	0.78
	Specificity	0.38	0.31	0.50	0.34	0.23
	Area under ROC curve at cut point	0.46	0.41	0.45	0.38	0.50
General disease	Optimal cut point	6,643	1.00	741	2	—
	Sensitivity	0.59	0.51	0.40	0.43	0.84
	Specificity	0.35	0.27	0.47	0.28	0.21
	Area under ROC curve at cut point	0.47	0.39	0.43	0.36	0.52

¹The farms were located in southern Ontario, Canada, and were visited once per season over a 1-yr period.

²ROC = receiver operator curve.

Table 3. Final generalized linear model identifying the association between changes in milk allotment consumption (%) and bovine respiratory disease (BRD) in group-housed preweaning dairy calves being fed via a Förster-Technik automated milk feeder (AMF)¹

Predictor variable	Relative proportion ratio	Robust SE	95% CI		P-value
			LCL ²	UCL ²	
Days on AMF					
0–12	Referent				
13–22	3.23	0.87	1.91	5.46	<0.001
23–35	1.97	0.44	1.27	3.04	0.002
36–56	2.06	0.44	1.28	3.32	0.003
Health status					
No BRD	Referent				
BRD	0.37	0.07	0.26	0.54	<0.001
Intercept	6.50	1.01	4.80	8.81	<0.001

¹The farms were located in southern Ontario, Canada, and visited once each season over a 1-yr period. A total of 507 calves were included in the model, 112 of which had BRD.

²LCL = lower confidence limit; UCL = upper confidence limit.

0.001) less per min, respectively, compared with calves without BRD, NCD, or general disease, respectively. The interclass correlation coefficient was 0.08, 0.07, and 0.08 in the models evaluating BRD, NCD, and general disease, respectively, implying much variation at the farm level. Changes in the drinking speed of calves had a sensitivity of 37, 41, and 40% and a specificity of 54, 50, and 47% in the detection of BRD, NCD, and general disease, respectively.

Time at the AMF

Calves spent an average of 40 min/d [range: 3–237 min; SD: 22 min] at the feeder. There were no signifi-

cant associations between the total time spent at the AMF and any of the measured diseases.

Rewarded and Unrewarded Visits to the AMF

The mean number of rewarded visits to the AMF per day was 5 (range: 1–29; SD: 3). There were no significant associations between the total number of daily rewarded visits and any of the measured diseases.

The mean number of unrewarded visits to the AMF per day was 7 (range: 0–81; SD: 10). Days on the AMF was a confounding variable for NCD and general disease, so it was forced into the final models. When days on the AMF was included, NCD was no longer associated

Table 4. Final generalized linear model evaluating the association between changes in milk allotment consumption (%) and neonatal calf diarrhea (NCD) in group-housed preweaning dairy calves being fed via a Förster-Technik automated milk feeder (AMF)

Predictor variable	Relative proportion ratio	Robust SE	95% CI		P-value
			LCL ²	UCL ²	
Days on AMF					
0–12	Referent				
13–22	2.68	0.71	1.59	4.52	<0.001
23–35	1.43	0.32	0.92	2.23	0.110
36–56	1.42	0.38	0.84	2.39	0.190
Age at introduction to AMF, d					
0–6	Referent				
7–10	0.82	0.19	0.53	1.28	0.387
11–37	0.56	0.12	0.36	0.86	0.009
Sex					
Female	Referent				
Male	0.65	0.13	0.44	0.96	0.029
Health status					
No NCD	Referent				
NCD	0.43	0.08	0.29	0.63	<0.001
Intercept	14.10	4.19	7.87	25.25	<0.001

¹The farms were located in southern Ontario, Canada, and visited once each season over a 1-yr period. A total of 507 calves were included in the model, 128 of which had NCD.

²LCL = lower confidence limit; UCL = upper confidence limit.

Table 5. Final generalized linear model evaluating the association between changes in milk allotment consumption (%) and general disease (one or more of BRD, NCD, or umbilical infection) in group-housed preweaning dairy calves being fed via a Förster-Technik automated milk feeder (AMF)¹

Predictor variable	Relative proportion ratio	Robust SE	95% CI		P-value
			LCL ²	UCL ²	
Days on AMF					
0–12	Referent				
13–22	2.68	0.71	1.59	4.50	<0.001
23–35	1.52	0.35	0.97	2.38	0.069
36–56	1.71	0.48	0.98	2.98	0.059
Health status					
Healthy	Referent				
General disease	0.50	0.16	0.27	0.93	0.029
Intercept	8.08	2.11	4.85	13.48	<0.001

¹The farms were located in southern Ontario, Canada, and visited once each session over a 1-yr period. A total of 507 calves were included in the model, 206 of which had general disease.

²LCL = lower confidence limit; UCL = upper confidence limit.

with the number of unrewarded visits. However, BRD and general disease were associated with the number of unrewarded visits, as shown in Table 6 and Table 7, respectively. A total of 516 calves were assessed in the BRD model, with 114 of those calves having BRD. In the general disease model, 516 calves were also evaluated, with 207 of those calves had general disease. Calves with BRD or general disease had approximately 2 fewer unrewarded visits than calves without BRD or general disease, respectively. The interclass correlation coefficients for the models evaluating BRD and general disease were 0.18 and 0.17, respectively. The number of unrewarded visits had a sensitivity of 35, 42, and 43% and a specificity of 40, 34, and 28% in detecting BRD, NCD, and general disease, respectively.

Parallel Testing

For each of BRD, NCD, and general disease, parameters that were significant in the final multivariable model were used in parallel testing. Specifically, the optimal threshold to classify BRD, NCD, and general disease, that was calculated for each parameter using Youden's index, was used in parallel testing. When the behaviors were interpreted in parallel, the sensitivity for detecting BRD, NCD, and general disease was 82, 78, and 84%, respectively, and the specificity for detecting BRD, NCD, and general disease was 26, 23, and 21%, respectively.

DISCUSSION

This study provides information on the associations between general disease and differences in feeding data at a single point in time in calves being fed via an AMF. When animals become ill, they manifest behavioral

and subjective psychological changes, which in addition to the fever response, constitute what is known as sickness behavior (Dantzer, 2009), which is a complex adaptive approach to surviving infections (Hart, 1988). This study identified associations between several feeding behaviors (milk consumption, percentage of milk allotment consumed, drinking speed, and the number of unrewarded visits) and one or more of BRD, NCD, and general disease. However, each of these associated variables had poor sensitivity and specificity, meaning that used alone, they had poor accuracy to identify sick calves.

Calf Health and Group Housing

Overall, 40% of calves were identified as having general disease, of which 25 and 22% had NCD and BRD, respectively. This was comparable to the prevalence of disease found by Cramer et al. (2016) in group-housed dairy calves (22 and 26%, for NCD and BRD, respectively). Similarly, Knauer et al. (2017) found a higher prevalence of NCD than BRD (31 and 12%, respectively) in all enrolled calves, however, their prevalence of BRD was much lower than what was found in this study. The difference found in the prevalence of disease was likely due to the difference in age of the calves in the study groups. The prevalence of NCD has been shown to typically be the highest in the calf's first month of life, whereas the prevalence of BRD is typically highest in the second and third month of life (Svensson et al., 2003). The average age of treatment in the Knauer et al. (2017) study was approximately 18 d (introduced to the group pen at 9.1 ± 5 d old with first treatments occurring 9.3 ± 8.5 d after introduction), which is representative of the age where the calves are most susceptible to NCD. Conversely, the median age of calves in this study and the Cramer et al. (2016) study

Table 6. Final mixed linear regression model evaluating the association between the number of unrewarded visits and calves with bovine respiratory disease (BRD) being raised in group pens with a Förster-Technik automated milk feeder (AMF)¹

Predictor variable	Coefficient	SE	95% CI		P-value
			LCL ²	UCL ²	
Days on AMF					
0–12	Referent				
13–22	2.16	0.97	0.26	4.05	0.026
23–35	3.54	0.96	1.66	5.42	<0.001
36–56	4.81	0.99	2.88	6.74	<0.001
Sex					
Female	Referent				
Male	–2.61	0.89	–4.36	–0.86	0.003
Health status					
No BRD	Referent				
BRD	–2.09	0.85	–3.75	–0.44	0.013
Intercept	6.09	1.69	2.79	9.40	<0.001

¹The farms were located in southern Ontario, Canada, and visited once each season over a 1-yr period. There were 516 calves included in the model, 114 of which had BRD.

²LCL = lower confidence limit; UCL = upper confidence limit.

was 33 and 35 d, respectively, which is representative of when calves are most susceptible to BRD.

Calf Feeding Plans

The feeding plans used by the farms in this study varied significantly with only 4 of the farms using ramp-up, hold, and ramp-down phases, with some of the plans varying by season. One farm used all 3 phases in the fall; however, for the remaining seasons, a hold phase was not used. Two farms did not use a ramp-up phase and 3 farms did not use a hold phase; however, all farms used a ramp-down phase. Of the farms that used a 3-stage feeding plan, they consisted of an average ramp-up phase of 16 d, a hold phase of 26 d, and a

ramp-down phase of 16 d. This differed from the feeding plan found in the Knauer et al. (2017) study, which had a ramp-up, hold, and ramp-down phase of 10, 30, and 13 d, respectively. Due to the calves being different ages the day the feeding behavior data were collected, the phase of the feeding plan in which the calf was in varied and therefore, so did their maximum daily milk allotment. This would have likely affected the feeding behaviors collected, as calves fed lower volumes of milk (4.8–6 vs. 9.2–12 L/d) have been shown to have more unrewarded visits to the AMF (Nielsen et al., 2008; Rosenberger et al., 2017). The models evaluating the number of unrewarded visits to the AMF captured this as older calves, who would have been in the ramp-down phase and therefore fed a lower volume of milk, had

Table 7. Final mixed linear regression model evaluating the association between the changes in the number of unrewarded visits and calves with general disease being raised in group pens with a Förster-Technik automated milk feeder (AMF)¹

Predictor variable	Coefficient	SE	95% CI		P-value
			LCL ²	UCL ²	
Days on AMF					
0–12	Referent				
13–22	1.78	0.96	–0.10	3.66	0.064
23–35	2.86	0.97	0.96	4.75	0.003
36–56	4.01	1.00	2.04	5.97	<0.001
Sex					
Female	Referent				
Male	–2.71	0.89	–4.46	–0.97	0.002
Health status					
Healthy	Referent				
General disease	–2.43	0.75	–3.90	–0.96	0.001
Intercept	7.17	1.69	3.87	10.48	<0.001

¹The farms were located in southern Ontario, Canada, and visited once each season over a 1-yr period. There were 514 calves included in the model, 207 of which had general disease.

²LCL = lower confidence limit; UCL = upper confidence limit.

significantly more unrewarded visits to the AMF than younger calves. Similarly, the number of days the calf was on the feeder also affected the percentage of milk allotment the calf consumed. This is due to calves being more likely to all consume the entirety of their milk allotment when they are fed lower volumes of milk as they are unable to reach satiation.

Association of Feeding Behaviors with Disease

This study found that calves with NCD and general disease drank significantly less milk than control calves; however, calves with BRD did not drink less milk. These findings are in agreement with Knauer et al. (2017), who found that there was a significant decrease in milk consumption of calves with NCD and general disease in the days leading up to and all days following diagnosis; however, there was no significant change in calves with BRD surrounding the treatment event. Borderas et al. (2009) found that there was only a difference in milk consumption between healthy and diseased calves (BRD or NCD or both) when they were fed a high volume of milk (12 L/d). Similarly, we found lower milk consumption in calves with general disease, although the calves had on average, a maximum allowable milk volume of 8.9 L/d (range: 8–12 L/d).

No studies have examined the percentage of milk that the calf has consumed from its daily milk allotment as a predictor variable for illness. However, it appears that this variable may be useful for disease detection. It is likely less useful on limit-fed diets (4 L/d) as the nutrient supply is closer to the maintenance requirement, so animals are less likely to reduce consumption during mild to moderate illness. For example, Borderas et al. (2009) found that sick calves that were fed a low volume of milk (4 L/d) had no change in milk consumption. As well, this variable may not be as meaningful during a ramp-up or ramp-down portion of the milk feeding phase.

We found no association between disease status and time spent at the AMF. This is in contrast to Borderas et al. (2009), where calves fed lower volumes of milk (4 L/d) spent less time at the feeder on the day of disease diagnosis and in the following week, whereas calves that were fed a high volume of milk (12 L/d) spent less time at the feeder only in the days after disease diagnosis. We acknowledge that our data were collected at a single point in time, so we cannot speak to differences before or after disease diagnosis. Moreover, we did not know how long calves had been sick or whether treatment had already been initiated. Furthermore, the type and duration of treatment may have affected the feeding behaviors of the calves. For example, calves older than 10 d old treated with meloxicam for NCD were 5.3 times

more likely to consume their entire milk allowance compared with calves treated with a placebo, when fed 4 L/d (Todd et al., 2010). In addition, the Borderas et al. (2009) study may have found a difference in total time spent at the AMF between sick and healthy calves as they matched their calves on feed allowance. That was not the case in this study which would have resulted in comparisons between calves that could have different feed allowances, depending on the age of the calf at the time of the assessment. This would reduce the comparability of the 2 studies as meal duration has been shown to decrease in calves fed restricted diets compared with calves fed ad libitum (Miller-Cushon et al., 2013).

The average drinking speed found in this study (744 ± 274 mL/min) was very similar to what was found by Cantor et al. (2019) (730 ± 500 mL/min); however, Knauer et al. (2017) reported an average drinking speed of 844 ± 344 mL/min across the entire study period. This difference in drinking speed could be a result of competition at the feeder as greater competition is associated with faster drinking speeds (Jensen, 2004). Results from previous studies have been varied as to whether or not drinking speed is reduced in diseased calves. Svensson and Jensen (2007) found that calves fed a maximum of 8.6 L of milk/d had no difference in drinking speed between healthy and diseased calves. Knauer et al. (2017) found that calves fed an average of 9.4 L (range: 7–16 L/d) of milk/d had lower drinking speed when they were diseased. Similarly, we found slower drinking speed in diseased calves fed an average of 8.9 L/d (range: 8–12 L/d). Despite these findings, drinking speed is not a useful tool in disease detection on its own, however in combination with other feeding behaviors, it may serve as a useful preliminary tool in detecting disease calves.

In agreement with other studies, the number of rewarded visits was not associated with disease. Knauer et al. (2017) found 4.3 ± 3.0 rewarded visits in healthy calves and 4.8 ± 3.1 visits in unhealthy calves, which was very similar to the average number of rewarded visits found in this study (5 ± 3). The lack of difference in the number of rewarded visits between sick and healthy calves is likely due to the fact that, despite disease, the sick calf is still motivated to consume enough milk required for maintenance energy. Although the healthy calves have the same number of rewarded visits, their faster drinking speed allows the calf to consume greater volumes of milk during those visits.

There were approximately 2 fewer unrewarded visits for calves with BRD and general disease compared with the control calves. Similarly, Knauer et al. (2017) found that diseased calves had 2.3 fewer unrewarded visits per day in the 10 d before and following disease diagnosis.

Knauer et al. (2017) also found that calves with NCD had fewer visits to the AMF from 2 d before diagnosis to 10 d after diagnosis and Johnston et al. (2016) found that calves with BRD had fewer unrewarded visits to the AMF in the 3 d before diagnosis. Calves fed a restricted diet had 12 times more unrewarded visits than calves fed *ad libitum*, suggesting that unrewarded visits can also be an indication of hunger (De Paula Vieira et al., 2008). Given the low discriminative ability in using unrewarded visits to identify disease, this behavior could be influenced by other parameters beyond disease.

Based on the low sensitivity and specificity in identifying disease with individual feed behaviors, we used parallel testing to determine the performance of using all of the feeding behaviors to detect disease. As expected, parallel testing increased the sensitivity of disease detection, however the specificity was greatly compromised. Thus, these feeding behaviors used in parallel could serve as a useful first step or adjunct method to producers in detecting diseased calves. Although the false positive rate would be high, using the feeding behavior data would identify which calves need further inspection or examination. It is important to note that although the feeding behaviors of calves at a single point in time cannot be used to detect diseased calves on its own, it can still serve as a useful preliminary tool in the disease detection process.

Limitations

There are several limitations to consider when interpreting the results of this study. One of the limitations is the potential introduction of selection bias due to the use of a convenience sample. Only looking at farms in southern Ontario reduced the external validity of the study as the sample may not have been representative of the entire population.

In addition, calves with BRD and NCD in this study were compared with calves without BRD and calves without NCD, respectively. This means that the comparator calves did not have to be healthy, they just could not have the disease of interest. This could have potentially biased the results toward the null because if the comparator calves were healthy, there would have likely been a larger difference in the feeding behaviors between healthy and diseased calves.

Information bias could have also occurred. No intra-observer reliability tests were completed by the researcher collecting the data which may have resulted in incorrectly health scoring the calves and therefore, misclassifying disease status. This would result in non-differential misclassification bias and would bias the results toward the null.

Additionally, a significant amount of variation at the farm level was observed. Most of the variation occurred could be due to differences in the number of calves per feeder and milk feeding plans. Specifically, competition for access to milk as larger group sizes (24 vs. 12 calves/pen) have been shown to result in increased drinking speed and decreased time at the feeder (Jensen, 2004). As discussed earlier, low planes of nutrition have been shown to increase the number of unrewarded visits (Nielsen et al., 2008; Rosenberger et al., 2017), which was evident in this study with the calves that were on the AMF the longest (36–56 d) having the greatest number of unrewarded visits.

Finally, an additional limitation of this study is the cross-sectional study design that resulted in feeding behaviors and health scores being recorded only on the single day researchers were present on the farm. Although we do not know the exact duration, calves could have had long-lasting disease, which would have affected the feeding behaviors. Previous work by Knauer et al. (2017) has shown that feeding behaviors change in the days surrounding a disease event. However, we believe the findings from this study holds merit as it yielded results that found a relationship between feeding behaviors and disease on the same day of health scoring.

CONCLUSIONS

The results of this cross-sectional study indicated that total daily milk consumption, percentage of milk allotment consumption, drinking speed and the number of unrewarded visits were associated with one or more of BRD, NCD, and general disease. However, none of these measures alone, assessed only concurrently with a single health assessment, had sufficient accuracy to serve as a useful diagnostic test. Although, when the feeding behaviors were assessed in parallel, the sensitivity of the detection of disease was greatly increased. Nonetheless, the AMF cannot stand alone in the detection of disease calves; however it can serve as a useful tool to producers to help identify calves that need further inspection when the feeding behaviors are measured in parallel. The results of the study may be useful to producers and veterinarians and has provided further insight to the utility of AMF and feeding behavior data of group-housed dairy calves.

ACKNOWLEDGMENTS

This research was supported by Food from Thought at the University of Guelph (Guelph, ON, Canada), which is funded in part by the Canada First Research

Excellence Fund. The authors have not stated any conflicts of interest.

REFERENCES

- Borderas, T. F., J. Rushen, M. A. G. von Keyserlingk, and A. M. B. de Passillé. 2009. Automated measurement of changes in feeding behavior of milk-fed calves associated with illness. *J. Dairy Sci.* 92:4549–4554. <https://doi.org/10.3168/jds.2009-2109>.
- Cantor, M. C., A. L. Stanton, D. K. Combs, and J. H. C. Costa. 2019. Effect of milk feeding strategy and lactic acid probiotics on growth and behaviour of dairy calves fed using an automated feeding system. *J. Anim. Sci.* 97:1052–1065.
- Costa, J. H. C., M. C. Cantor, and H. W. Neave. 2021 Symposium review: Precision technologies for dairy calves and management applications. *J. Dairy Sci.* <https://doi.org/10.3168/jds.2019-17885>.
- Cramer, M. C., T. L. Ollivett, and A. L. Stanton. 2016. Associations of behavior-based measurements and clinical disease in pre-weaned, group-housed dairy calves. *J. Dairy Sci.* 99:7434–7443. <https://doi.org/10.3168/jds.2015-10207>.
- Dantzer, R. 2009. Cytokine, sickness behavior and depression. *Immunol. Allergy Clin. North Am.* 29:247–264. <https://doi.org/10.1016/j.iac.2009.02.002>.
- De Paula Vieira, A., V. Guesdon, A. M. de Passillé, M. A. G. von Keyserlingk, and D. M. Weary. 2008. Behavioral indicators of hunger in dairy calves. *Appl. Anim. Behav. Sci.* 109:180–189. <https://doi.org/10.1016/j.applanim.2007.03.006>.
- Hart, B. L. 1988. Biological basis of the behavior of sick animals. *Neurosci. Biobehav. Rev.* 12:123–137. [https://doi.org/10.1016/S0149-7634\(88\)80004-6](https://doi.org/10.1016/S0149-7634(88)80004-6).
- Jensen, M. B. 2004. Computer-controlled milk feeding of dairy calves: The effects of number of calves per feeder and number of milk portions on use of feeder and social behavior. *J. Dairy Sci.* 87:3428–3438. [https://doi.org/10.3168/jds.S0022-0302\(04\)73478-5](https://doi.org/10.3168/jds.S0022-0302(04)73478-5).
- Jensen, M. B., and D. S. Weary. 2013. Group housing and milk feeding of dairy calves. *WCDS Adv. Dairy Technol.* 25:179–189.
- Johnston, D., D. A. Kenny, M. McGee, S. M. Waters, A. K. Kelly, and B. Earley. 2016. Electronic feeding behavioral data as indicators of health status in dairy calves. *Ir. J. Agric. Food Res.* 55:159–168. <https://doi.org/10.1515/ijaf-2016-0016>.
- Karle, B. M., G. U. Maier, W. J. Love, S. A. Dubrovsky, D. R. Williams, R. J. Anderson, A. L. Van Eenennaam, T. W. Lehenbauer, and S. S. Aly. 2019. Regional management practices and prevalence of bovine respiratory disease in California's pre-weaned dairy calves. *J. Dairy Sci.* 102:7583–7596. <https://doi.org/10.3168/jds.2018-14775>.
- Knauer, W. A., S. M. Godden, A. Dietrich, and R. E. James. 2017. The association between daily average feeding behaviors and morbidity in automatically fed group-housed preweaned dairy calves. *J. Dairy Sci.* 100:5642–5652. <https://doi.org/10.3168/jds.2016-12372>.
- Kung, L. Jr., S. Demarco, L. N. Siebenson, E. Joyner, G. F. W. Haenlein, and R. M. Morris. 1997. An evaluation of two management systems for rearing calves fed milk replacer. *J. Dairy Sci.* 80:2529–2533. [https://doi.org/10.3168/jds.S0022-0302\(97\)76206-4](https://doi.org/10.3168/jds.S0022-0302(97)76206-4).
- McGuirk, S. M. 2008. Disease management of dairy calves and heifers. *Vet. Clin. North Am. Food Anim. Pract.* 24:139–153. <https://doi.org/10.1016/j.cvfa.2007.10.003>.
- McGuirk, S. M., and S. F. Peek. 2014. Timely diagnosis of dairy calf respiratory disease using a standardized scoring system. *Anim. Health Res. Rev.* 15:145–147. <https://doi.org/10.1017/S1466252314000267>.
- Medrano-Galarza, C., S. J. LeBlanc, T. J. DeVries, A. Jones-Bitton, J. Rushen, A. M. de Passillé, and D. B. Haley. 2017. A survey of dairy calf management practices among farms using manual and automated milk feeding systems in Canada. *J. Dairy Sci.* 100:6872–6884. <https://doi.org/10.3168/jds.2016-12273>.
- Medrano-Galarza, C., S. J. LeBlanc, A. Jones-Bitton, T. J. DeVries, J. Rushen, A. M. de Passillé, and D. B. Haley. 2018a. Producer perceptions of manual and automated milk feeding systems for dairy calves in Canada. *Can. J. Anim. Sci.* 98:250–259. <https://doi.org/10.1139/cjas-2017-0038>.
- Medrano-Galarza, C., S. J. LeBlanc, A. Jones-Bitton, T. J. DeVries, J. Rushen, A. M. de Passillé, M. I. Endres, and D. B. Haley. 2018b. Associations between management practices and within-pen prevalence of calf diarrhea and respiratory disease on dairy farms using automatic milk feeders. *J. Dairy Sci.* 101:2293–2308. <https://doi.org/10.3168/jds.2017-13733>.
- Miller-Cushon, E. K., R. Bergeron, K. E. Leslie, and T. J. De Vries. 2013. Effect of milk feeding level on development of feeding behavior in dairy calves. *J. Dairy Sci.* 96:551–564. <https://doi.org/10.3168/jds.2012-5937>.
- Nielsen, P. P., M. B. Jensen, and L. Lidfors. 2008. Milk allowance and weaning method affect the use of a computer-controlled milk feeder and the development of cross-sucking in dairy calves. *Appl. Anim. Behav.* 109:223–237. <https://doi.org/10.1016/j.applanim.2007.01.015>.
- Rosenberger, K., J. H. C. Costa, H. W. Neave, M. A. G. von Keyserlingk, and D. M. Weary. 2017. The effect of milk allowance on behavior and weight gains in dairy calves. *J. Dairy Sci.* 100:504–512. <https://doi.org/10.3168/jds.2016-11195>.
- Sutherland, M. A., G. L. Lowe, F. J. Huddart, J. R. Waas, and M. Stewart. 2018. Measurement of dairy calf behavior prior to onset of clinical disease and in response to disbudding using automated calf feeders and accelerometers. *J. Dairy Sci.* 101:8208–8216. <https://doi.org/10.3168/jds.2017-14207>.
- Svensson, C., and M. B. Jensen. 2007. Short communication: Identification of diseased calves by use of data from automatic milk feeders. *J. Dairy Sci.* 90:994–997. [https://doi.org/10.3168/jds.S0022-0302\(07\)71584-9](https://doi.org/10.3168/jds.S0022-0302(07)71584-9).
- Svensson, C., K. Lundborg, U. Emanuelson, and S.-O. Olsson. 2003. Morbidity in Swedish dairy calves from birth to 90 days of age and individual calf-level risk factors for infectious diseases. *Prev. Vet. Med.* 58:179–197. [https://doi.org/10.1016/S0167-5877\(03\)00046-1](https://doi.org/10.1016/S0167-5877(03)00046-1).
- Swartz, T. H., A. N. Findlay, and C. S. Petersson-Wolfe. 2017. Short communication: Automated detection of behavioral changes from respiratory disease in pre-weaned calves. *J. Dairy Sci.* 100:9273–9278. <https://doi.org/10.3168/jds.2016-12280>.
- Todd, C. G., S. T. Millman, D. R. McKnight, T. F. Duffield, and K. E. Leslie. 2010. Nonsteroidal anti-inflammatory drug therapy for neonatal calf diarrhea complex: Effects on calf performance. *J. Anim. Sci.* 88:2019–2028. <https://doi.org/10.2527/jas.2009-2340>.
- University of Wisconsin-Madison. 2021. Food Animal Production Medicine – Calf Health Scorer. Accessed Feb. 23, 2021. <https://www.vetmed.wisc.edu/fapm/svm-dairy-apps/calf-health-scorer-chs/>.
- Vasseur, E., F. Borderas, R. I. Cue, D. Lefebvre, D. Pellerin, J. Rushen, K. M. Wade, and A. M. de Passillé. 2010. A survey of dairy calf management practices in Canada that affect animal welfare. *J. Dairy Sci.* 93:1307–1316. <https://doi.org/10.3168/jds.2009-2429>.
- von Elm, E., D. G. Altman, M. Egger, S. J. Pocock, P. C. Gøtzsche, and J. P. Vandenbroucke. 2008. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: Guideline for reporting observational studies. *J. Clin. Epidemiol.* 61:344–349. <https://doi.org/10.1016/j.jclinepi.2007.11.008>.

ORCID

- M. H. Conboy <https://orcid.org/0000-0003-4613-2503>
 C. B. Winder <https://orcid.org/0000-0002-7314-3657>
 C. Medrano-Galarza <https://orcid.org/0000-0002-2690-189X>
 S. J. LeBlanc <https://orcid.org/0000-0003-2027-7704>
 D. B. Haley <https://orcid.org/0000-0003-3502-120X>
 J. H. C. Costa <https://orcid.org/0000-0001-9311-4741>
 M. A. Steele <https://orcid.org/0000-0001-6941-6205>
 D. L. Renaud <https://orcid.org/0000-0002-3439-3987>