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Evaluation of applying statistical process control techniques to daily average feeding behaviors to detect disease in automatically fed group-housed preweaned dairy calves

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ABSTRACT

Group housing and computerized feeding of preweaned dairy calves are gaining in popularity among dairy producers, yet disease detection remains a challenge for this management system. The aim of this study was to investigate the application of statistical process control charting techniques to daily average feeding behavior to predict and detect illness and to describe the diagnostic test characteristics of using this technique to find a sick calf compared with detection by calf personnel. This prospective cross-sectional study was conducted on 10 farms in Minnesota (n = 4) and Virginia (n = 6) utilizing group housing and computerized feeding from February until October 2014. Calves were enrolled upon entrance to the group pen. Calf personnel recorded morbidity and mortality events. Farms were visited either every week (MN) or every other week (VA) to collect calf enrollment data, computer-derived feeding behavior data, and calf personnel–recorded calf morbidity and mortality. Standardized self-starting cumulative sum (CUSUM) charts were generated for each calf for each daily average feeding behavior, including drinking speed (mL/min), milk consumption (L/d), and visits to the feeder without a milk meal (no.). A testing subset of 352 calves (176 treated, 176 healthy) was first used to find CUSUM chart parameters that provided the highest diagnostic test sensitivity and best signal timing, which were then applied to all calves (n = 1,052). Generalized estimating equations were used to estimate the diagnostic test characteristics of a single negative mean CUSUM chart signal to detect a sick calf for a single feeding behavior. Combinations of feeding behavior signals were also explored. Single signals and combinations of signals that included drinking speed provided the most sensitive and timely signal, finding a sick calf up to an average (±SE) of 3.1 ± 8.8 d before calf personnel. However, there was no clear advantage to using CUSUM charting over calf observation for any one feeding behavior or combination of feeding behaviors when predictive values were considered. The results of this study suggest that, for the feeding behaviors monitored, the use of CUSUM control charts does not provide sufficient sensitivity or predictive values to detect a sick calf in a timely manner compared with calf personnel. This approach to examining daily average feeding behaviors cannot take the place of careful daily observation.
Key words: group housing, feeding behavior, calf health, statistical process control

INTRODUCTION

Group housing and computerized feeding of dairy calves during the preweaning period are gaining in popularity among dairy producers worldwide, with an estimated 15% of preweaned dairy calves in the United States housed in groups (USDA-NAHMS, 2016). Computerized milk feeding systems offer an easy method to deliver more milk (Huuskonen and Khalili, 2008; Roth et al., 2008), reductions in labor needed per calf (Kung et al., 1997), and social benefits for the calf (Jensen et al., 1999; De Paula Vieira et al., 2012). However, morbidity (Svensson et al., 2003) and mortality risks (Losinger and Heinrichs, 1997) are significantly increased in large groups (≥7 calves) compared with small groups. Additionally, timely disease detection can be a challenge for calves housed in groups (Steenkamer, 1982; Cramer et al., 2016). Therefore, management tools and strategies that can help dairy producers predict and detect disease are of great interest for producers who use this calf rearing strategy.

One potential solution to the challenge of disease detection is that computer software can record and report

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individual calf feeding behaviors that may be associated with illness. For example, the Kalb Manager feeding software program (Förster-Technik, Engen, Germany) provides the producer with an alert when an individual calf deviates in its 3-d average drinking speed or milk consumption by 25% (Jan Zimerick, Förster-Technik North America, Cambridge, ON, Canada; personal communication). However, the accuracy and timeliness of current algorithms to detect disease are unknown. For example, in one observational study Borderas et al. (2009) found that calves fed a high level of milk (>8 L/d) decreased their daily average milk intake (consumption, **CON**; L/d) on the same day that they were detected as sick by a trained human observer. Furthermore, in the same study, calves offered a restricted level of milk (4 L/d) did not reduce their daily average milk intake at all during a period of illness. In another study, Svensson and Jensen (2007) reported that sick calves had a reduction in the number of visits to the feeder without a milk meal (unrewarded visits, **URV**; visits/d), but there was no difference between sick and healthy calves in the speed of milk CON (drinking speed, **DS**; mL/min) or rewarded visits (**RV**; visits/d) to the feeder. These studies suggest that current computer feeder software algorithms that use daily averages may have limited utility as an indicator of disease onset in that they lack in sensitivity compared with a trained human observer. However, a different approach to evaluate changes in feeding behavior in individual animals could result in a more sensitive and timely monitoring technique to detect morbidity in group-housed calves, which could result in prompt treatment and improved calf performance.

Statistical process control (**SPC**) is an analytical approach traditionally used in manufacturing process monitoring that uses control charts to differentiate common cause from special cause variation in a process over time (Hawkins and Olwell, 1998). Common cause variation represents the normal variation in any system over time. For example, the average calf may drink at a speed of 1,000 mL/min overall, but she may vary from 800 to 1,200 mL/min depending on unexplained environmental and individual calf factors. If her DS suddenly decreased to 200 mL/min, this could represent special cause variation, which can be the result of a health event, human error, or technical failure (Mertens et al., 2011). With the advent of precision livestock farming and the abundance of sensor-derived information, efforts have been made in the past decade to apply these analytical techniques to production data to monitor health (De Vries and Reneau, 2010). For example, by applying self-starting cumulative sum (**CUSUM**) control charts to steer feeding time, Quimby et al. (2001) reported that they could detect a sick feeder calf up to 4.5 d earlier than an experienced pen rider. Madsen and Kristensen (2005) applied similar methodologies to pen-level water intake in piglets and found that they could predict a diarrheal outbreak 1 d before clinical signs were observed. There can be value in finding these animals early in the disease process through the potential reduction of progression of disease by prompt intervention.

Traditionally, control charting has been used in manufacturing where historical data were available and common cause variation was minimal. However, certain challenges are introduced when we consider applying this approach to biological systems. For example, when a calf enters a group pen, we have no historical data on its behavior yet want to begin monitoring as soon as possible because disease can occur early in the feeding period. Self-starting cumulative sum control charts may be useful to address this problem (Hawkins and Olwell, 1998). In this procedure, the first several observations are used to establish the process mean and variance, and then both are updated with each new observation. These charts also have an advantage over other charting methods in that they are sensitive to small shifts, which are particularly of interest in biological processes (Mertens et al., 2011). The sensitivity of the chart to signal is determined by the upper and lower control limits, defined as the multiples of the SD by which the calculated CUSUM statistic is allowed to vary. When this value falls outside the upper or lower limits as predetermined by the user, the process is then investigated.

The objective of this study was to evaluate the sensitivity and timeliness of applying CUSUM charting techniques to computer feeder sensor–derived daily averages of dairy calf feeding behaviors to find a sick calf compared with trained calf personnel. We hypothesized that the application of CUSUM charting techniques to daily average individual calf feeding behavior data, alone or in combination, would be useful to detect a sick calf in a timely and sensitive manner compared with trained calf personnel. If successful, we anticipated that this technique could be applied to calf feeding behaviors in computer feeder software algorithms as a screening test to aid producers in the detection of sick calves in the field.

MATERIALS AND METHODS

The use of animals in the study was approved by the University of Minnesota Institutional Animal Care and Use Committee (protocol no. 1308-30844A). This manuscript was prepared according to the Standards for Reporting of Diagnostic Accuracy Studies (Bossuyt et al., 2015).