Precision Dairy Monitoring of Fresh Cows

Amanda E. Stone, I-Ching Tsai, and Jeffrey M. Bewley
University of Kentucky
Department of Animal and Food Sciences
407 WP Garrigus Building
Lexington, KY 40546-0215
Phone: 859-257-7543
Email: jbewley@uky.edu

Introduction

Dairy cow health is multifactorial and complex. High producing dairy cows have been described as "metabolic athletes," but 30 to 50% of cows are affected by a metabolic or infectious disease around calving (LeBlanc, 2010). Cows are highly susceptible to metabolic and infectious disease during the transition period, or the period from 3 weeks before to 3 weeks after calving (Huzzey et al., 2007, Mulligan and Doherty, 2008). The transition period is marked by a series of adaptations to the demands of lactation. These adaptations are described as homeorhetic, or long term physiological adaptations to changes in state (i.e. the transition from dry to lactating) (DeGaris and Lean, 2009). Transition dairy cows are immunosuppressed and often have to deal with sudden dietary changes that cause metabolic problems. This fragile group of cows is also likely to experience environmental stressors, like routine group changes that are associated with dairy farm management of dry and lactating cows. These effects combined with the stress of parturition lead to a period of great risk for production diseases right after parturition. Dairy cow diseases signify a cow's inability to cope with the metabolic demands of high production. Unfortunately, these diseases cause economic losses to the dairy industry and are an animal welfare concern (Mulligan and Doherty, 2008).

Ketosis, fatty liver, hypocalcemia, retained placenta, metritis, and displaced abomasums are linked etiologically. Unfortunately, this interrelationship regularly results in "cascade effects" that increase the incidence of infectious and production diseases, reduce fertility, reduce milk production, and increase lameness incidence. The complex interaction of transition cow diseases, their relationship with nutrition, and their effects on social behavior and attitude make prevention and control of these diseases difficult (Mulligan and Doherty, 2008). Metabolic events starting two weeks before calving have effects on reproductive performance months later (LeBlanc, 2010). Therefore, early identification of disease may be especially useful during this time (Huzzey et al., 2007, LeBlanc, 2010).

The probability of death is highest in the first month of lactation for both primiparous and multiparous cows. Cows are under great metabolic stress during this time and may be more vulnerable to disease. Risk factors for death in this period include retained placenta, milk fever, displaced abomasum, and mastitis for multiparous cows. Risk factors for death in the first month of lactation in primiparous cows include mastitis, retained placenta, and displaced abomasum. Milk fever, ketosis, and displaced abomasum increased the risk of culling while, interestingly, retained placenta decreased the risk (Hertl et al., 2011).

Disease detection using Precision Dairy Monitoring technologies

As average herd size increases, time producers can devote to each animal decreases (Schulze et al., 2007, Ipema et al., 2008, Bewley, 2010, Brandt et al., 2010) as the administrative, technical, organizational, and logistic workload for the producer increases (Berckmans, 2004). Livestock production today requires the desire to look beyond economic goals (Frost et al., 2003, Berckmans, 2004). Consumer pressure and concern for animal well-being and health, efficient and sustainable farming, food safety and quality, and control of zoonotic diseases, pathogens, and medical treatments has altered decision-making processes on farms (Berckmans, 2004, Schukken et al., 2008, Bewley, 2010). Dairy operations also have narrower profit margins than in the past because the government is less involved in regulating agricultural commodity prices. Because of these major industry shifts, on-farm decision making is changing and dairy cow monitoring tools will likely increase in importance (Berckmans, 2004, Schulze et al., 2007, Ipema et al., 2008, Bewley, 2010) to help make decisions that previously were based solely on producer experience and judgement. Unfortunately, on-farm decisions are riddled with complexities, many of which the effects have to be estimated or guessed at by the producers (Frost et al., 2003). One way to counteract these problems is through the use of automated monitoring systems (Chagunda et al., 2006b).

Throughout history, agricultural techniques have advanced to support larger populations, with the growth of the non-farming population alongside an increase in living standards, agriculture’s role and function has been transformed (Marchesi, 2012). Precision agriculture refers to the use of technologies to increase efficiency and reduce environmental damage in crop farming. Precision livestock farming applies the precision agriculture principles to animals, focusing on individual animal production and environmental impact (Laca, 2009). One goal of precision livestock farming to develop in-line systems that monitor animals objectively, continuously, and automatically, without adding stress on the animals (Berckmans, 2004). Precision Dairy Monitoring (PDM) is the use of technologies to measure physiological, behavioral, and production indicators on individual animals to improve management and farm performance (Bewley, 2010, 2012). This type of management system relies on the observation that the animal herself is the important part of the biological production process at hand (Berckmans, 2004).

Objective physiological measures of animal responses to environmental stressors can be used to evaluate the degree of stress and consequent adaptations to that stress (Hahn et al., 1990). Animals are complex and respond differently at different moments of time compared to their herdmates. Outside of precision livestock farming, animals are commonly considered an “average of a population” thus creating a steady-state system. Within precision livestock farming, however, each animal can be treated as its own CIT system (Complex, Individual, and Time-variant) (Berckmans, 2004). Real-time data from PDM technologies could be incorporated into decision support systems to facilitate decision making when multiple data sources are necessary (Bewley, 2010).

The goals of PDM are maximizing individual animal potential, early disease detection, and maximizing preventive care instead of medical treatments. Perceived benefits of PDM technologies include increased efficiency, reduced costs, improved milk quality, minimized environmental impacts, and improved animal health and well-being. Additionally, information from PDM technologies could potentially be incorporated into genetic evaluations for traits targeted at improving subsequent generations' health, well-being, and longevity (Bewley, 2010).
Marchesi (2012) explained that implementing an animal monitoring system is both a moral and commercial interest to producers because it helps them satisfy the animal's needs.

To date, PDM evaluations have focused mainly on automated estrus detection, aimed to supplement or replace visual estrus detection (Dolecheck et al., 2015). Precision Dairy Monitoring technologies also have the potential to detect disease early, maximizing individual animal potential. Disease detection in the past has relied on producers observing clinical signs, but once clinical signs are displayed, it is often too late to act effectively. Clinical signs are often preceded by physiological changes that are undetectable with human senses, but may be possible with PDM and could allow producers to intervene sooner. Technologies may alert producers to cows at risk for a disease instead of the existing disease detection method of identifying cows that are already sick (Itle et al., 2015).

Many disease cases go unnoticed because veterinary examination is the gold standard of disease detection, are conducted relatively infrequently on most dairy farms (Urton et al., 2005). Instead, dairy producers often rely on their experience and judgement to identify sick animals, but human perception of a cow's condition is limited. Additionally, some diseases do not present obvious signs (Weary et al., 2009). Even worse, sometimes, by the time an animal does display outward signs of illness or stress, it is too late to intervene. Physiological changes typically occur before clinical symptoms, though. If a producer were able to detect these physiological changes, interventions could occur sooner. Even when individual monitoring is employed on farms, behavioral indicators used to detect illness are often based simply on the experience and intuition of the producer and tend to be unreliable (Weary et al., 2009).

Producers can examine real time data and reports to identify abnormal deviations from a baseline (Bewley, 2010). However, the data itself is meaningless unless it is transformed into a good decision management program. Thus, the producer remains a critical factor in good animal management and technologies will only support, not replace, the producer (DeGaris and Lean, 2009, Bewley, 2010, Marchesi, 2012). The ability to combine computer systems with the strengths and abilities of the producer is where the potential benefits of PDM systems lie (Marchesi, 2012). However, to achieve success using precision livestock farming processes, three conditions apply. First, animal variables should be monitored continuously and the data should be analyzed consistently. The definition of "continuously" depends on the animal variable of interest, like weight, activity, drinking and feeding behavior, feed intake, body temperature, etc. Second, a reliable prediction or expectation on how the animal will respond to the change must be available constantly. Lastly, this prediction should be coupled with the technology measurements in an algorithm to monitor or manage the animals automatically, and to monitor animal health or welfare or make desired system changes (Berckmans, 2004).

Often, each individual process involved in livestock production is controlled separately. Integrated management systems can control multiple, and ideally all, the interrelated processes involved in production. Each of the various processes within a dairy is usually controlled by one or more open-loop control systems, which has limited consideration for the effects that it has on other parts of the process. Management systems where various processes are integrated so that the production system is managed as a whole closed-loop system is a solution to the problems current systems being used on-farm create (Frost et al., 2003).

Sensors fall into two categories, attached and non-attached. Attached sensors would be the sensor on or inside the cow's body. Non-attached sensors would be off a cow's body measuring as a cow walks past or through the devices, or a sample taken to run an analysis. The developed sensor systems are divided into four different levels, (I) capability of measuring behavior about the cow (e.g. activity); (II) interpreting and summarizing the change of sensor data (e.g. increase in activity) in order to provide information of cow status (e.g. estrus); (III) combining information (e.g. economic information) and produce advice (e.g. whether to inseminate a cow or not); (IV) making decision autonomously of producers or sensors (e.g. the inseminator is called) (Rutten et al., 2013). Daily milk yield recording, milk component monitoring, pedometers, automatic temperature recording devices, milk electrical conductivity monitors, and automatic estrus detection monitors, and daily body weight systems are currently available for producers to implement on-farm. PDM systems may also be able to measure: jaw movements, ruminal pH, reticular contractions, heart rate, animal positioning and activity, vaginal mucus and electrical resistance, feeding behavior, lying behavior, odor, glucose, acoustics, progesterone, individual milk components, color, infrared udder surface temperatures, and respiration rates. Because the rapid development and availability of new PDM continues to grow, they are becoming more feasible for producers to implement in their own herds.

Although the technology required to achieve fully automated dairy systems is available, multidisciplinary and innovative research is required to achieve its application. The bottleneck for application is the availability of reliable sensor systems because the required algorithms to go along with them can be developed (Berckmans, 2004). Unfortunately, the dairy industry is relatively small, which limits corporate willingness to invest in developing technologies exclusively for dairy farms. Thus, technology development is instead driven by the availability of a technology in other industries and then transferred to the dairy industry, regardless of the actual needs.

Precision Dairy Monitoring technologies provide great opportunities to improve dairy herd management systems and may improve individual animal management (Bewley, 2010, Singh et al., 2014). However, the data itself is not useful unless it is interpreted and used effectively in decision making (Bewley, 2012, Singh et al., 2014). Most data management systems currently available are not used to their full potential. Other PDM limitations include: slow adoption rates, erroneous animal reads, equipment failure, the amount of data may overwhelm systems during data transfer, a lack of validated research results, and cows are normally housed in a restricted spatial area (Singh et al., 2014).

Variables measured by Precision Dairy Monitoring technologies

Temperature. Body temperature is influenced by health, environment, ambient temperature, eating behavior, drinking behavior, estrus, and the pregnancy status of an animal (Bewley et al., 2008). Fever, or a body temperature over a predefined threshold, is an indicator of disease (Leon, 2002, Burfeind et al., 2010). Fever is a complex physiological response to infection and inflammation. Once the body recognizes a pathogen invasion, macrophages and other immune cells release cytokines which signal the hypothalamus to increase the thermal set point. Although the mechanism of cytokine action remains unclear through studies in mice, this reaction causes body temperature to increase to match the increased thermal set point (Leon, 2002).

Producers often implement rectal temperature recording into their disease detection system (Schutz and Bewley, 2009, Burfeind et al., 2010, Vickers et al., 2010). The accuracy of commercially available electronic rectal thermometers is within 0.1°C (Vickers et al., 2010). However, several limitations to rectal temperature recording do exist. The first is that the presence of the recorder may affect temperature by making the animal nervous (Simmons et al., 1965, Bewley and Schutz, 2010). Other limitations include air in the rectum, failure to insert the probe deeply, and the creation of ulcers in the rectum from forceful insertion. Ambient temperature also has an effect and accuracy is related to the competency of the recorder (Aalseth, 2005).

Fever is described as a rise in body temperature above the "normal" range. Fever is a common, but complex, physiological response to infection, inflammation, and trauma aimed at the host's survival (Leon, 2002). Generally, average daily body temperatures for cattle fall within a range of 38 to 39.4°C (Lefcourt et al., 1999, Aalseth, 2005, Benzaquen et al., 2007). Temperatures can vary between individual cows in the same conditions and can vary within cows throughout a day (Simmons et al., 1965, Lefcourt et al., 1999).

Manual collection of rectal temperatures is the most common method of obtaining body temperatures in practice because of the ease of measurement and low purchase costs of rectal thermometers (Aalseth, 2005). Furthermore, because restraining animals to collect temperature data by manual means may cause stress that alters temperature, a reliable method of collecting temperatures without human intervention is likely to provide a more accurate measure of temperature in dairy cattle (Hahn et al., 1990). Pararectal temperature rose when the four study cows stood and decreased when they laid down. The opposite occurred in subcutaneous temperature where a thermometer was placed under the skin behind the shoulder (Simmons et al., 1965).

Firk et al. (2002) suggested that the value of a temperature monitor is highly dependent on its location. Body temperature has been monitored in dairy cattle in several anatomical locations including the rectum, tympanic and skin portion of the ear, vagina, reticulorumen, intraperitoneal cavity, udder skin, and milk. Internal temperature measurement sites may be more useful indicators of body temperature because they are not as readily affected by ambient conditions (Hahn et al., 1990). However, water consumption temporarily, but dramatically, decreases reticulorumen temperatures (Simmons et al., 1965, Brod et al., 1982, Bewley et al., 2008). In fistulated sheep, microbial activity decreased when injected intra-ruminally with 2 liters of 0°C water, which did not occur for the 10, 20, and 30°C water treatments. For the 0, 10, 20 and 30°C water treatments, temperatures did not return within ± 0.5°C to baseline rumen temperature for 108, 96, 96 and 72 minutes (Brod et al., 1982).

Simmons et al. (1965) cited that the mean pararectal, subcutaneous, and reticular temperatures over four days were 38.4 ± 0.3°C, 35.6 ± .8°C, and 38.8 ± 1.2°C., respectively. Pararectal and subcutaneous temperatures consistently dropped between 6 pm and 7:30 pm, likely related to water ingestion. One cow on the study showed greater variation in her pararectal and subcutaneous temperatures than the other cows. Observationally, she drank more often throughout the day and had a more nervous temperament than the other three, which the authors stated as a reason for her temperature variation.

In a Canadian study evaluating rectal temperature measurements to determine intra- and interinvestigator variability and to determine the effects of penetration depth into the rectum and defecation on measured body temperature, repeated rectal temperatures by a single researcher were consistent (39.5 ± 0.1°C). Correlation between two researchers was high ($r = 0.98$; $P < 0.001$). However, temperatures were 0.4°C ± 0.2°C greater when the probe was inserted deeper into the rectum ($P < 0.001$). Temperature around defecation varied, with some cows having a difference of ≥ 3.0°C after defecation while others had a difference of ≥ 3.0°C before defecation and some had no difference before or after defecation (Burfeind et al., 2010). Reticular temperatures decrease when cows drink water and take 1.5 (Simmons et al., 1965) to 3.5 hours (Bewley et al., 2008) to return to the pre-drinking temperature. Simmons et al. (1965) observed reticular temperatures as low as 32°C after water consumption.

Automatic temperature recording may allow producers to detect disease, estrus, heat stress, and the onset of calving earlier than currently possible (Bewley et al., 2008). Body temperature has commonly been used to detect fever, heat stress, and the onset of calving for many years. However, core body temperature is desired, but is fundamentally difficult to obtain and rectal temperature only approximates core body temperature. Taking rectal temperatures may cause stress that alters the temperatures so a reliable method with no human intervention may be a more accurate measure. Attempts to measure body temperature of cattle have been made at various anatomical locations including rectum, ear (tympanic), vagina, reticulum-rumen, and milk (Bewley and Schutz, 2010).

Adams et al. (2013) explained that cows with clinical mastitis had 6.7 times higher odds of having a reticulorumen temperature 0.8°C above their baseline within 4 days of diagnosis compared to control cows (76.9% specificity and 67.0% sensitivity). However, reticulorumen temperature was not different for cows diagnosed with metritis compared to control cows. Cows with retained placentas averaged 0.1°C greater temperature than matched control cows ($P < 0.001$) (Vickers et al., 2010).

Cows with puerperal metritis underwent a significant rectal temperature increase 24 hours before clinical signs (reaching 39.2 ± 0.05°C on the day of clinical diagnosis) (Benzaquen et al., 2007).

In a Canadian study, rectal and vaginal temperatures were highly correlated ($r = 0.81$; $P < 0.01$) in the 1,393 temperatures recorded for 29 fresh cows. However, rectal and vaginal temperatures were only moderately correlated ($r = 0.46$; $P < 0.01$) for the 556 temperatures recorded from the 13 peak lactation cows in this study. The correlation difference may have been because the fresh cows exhibited a larger temperature range (37.7 to 40.5°C) compared with peak-lactation cows (37.9 to 39.6°C) (Vickers et al., 2010). Healthy cows and cows with retained placentas both showed diurnal rhythms in their vaginal and rectal temperatures, with increases in the afternoon and decreases during the morning (Vickers et al., 2010). Diurnal variations in temperatures may be attributed to individual cow or breed characteristics and ambient weather conditions (Bewley et al., 2008). Some limitations to vaginal temperature monitoring are logger movement (particularly around calving when the vaginal cavity was enlarged), influx of ambient air, expulsion from the vagina (Vickers et al., 2010).

Reticular temperatures were lowest between noon and 4:00 PM (39.4°C) and between 8:00 AM and noon (39.5°C). In contrast, reticular temperatures were greatest between 8:00 PM and midnight (40.2°C) and between midnight and 4:00 AM (40.3°C) (Ipema et al., 2008). In an E. coli intramammary mastitis challenge, ruminal temperature peaked between 40.5°C and 41.0°C and remained above 40.0°C for two hours (AlZahal et al., 2011). Reticular temperature of cows diagnosed with mastitis deviated more than 3 standard deviations from baseline temperature in 45.7% of cows in another study (Bewley and Schutz, 2010).

Lying time and activity. Accelerometers measure three different movements: side-to-side, up and down, and front to back, and are thus provide more information than pedometers. A decrease in activity could be a sign of illness (Marchesi, 2012).

In dairy cattle, lying down is a high-priority behavior, which ensures that the necessary time to rest and ruminate is achieved. Danish researchers restricted time to feed access and explained that this restriction decreased time spent on all activities, but the proportion of time spent feeding and time spent on social contact remained constant. Yet the proportion of time spent lying increased. Therefore, the authors concluded that the priority for the behaviors studied were lying, followed by eating and social contact (Munksgaard et al., 2005). Lying time has been referenced between 10.5 and 11 hours per cow per day (Ito et al., 2009, Bewley et al., 2010c, Cyples et al., 2012, Medrano-Galarza et al., 2012).

Researchers contend that many behavioral signs shown by sick animals indicate the start of an action to fight off disease (Hart, 1988, Dantzer, 2004). Behavior is a crucial indicator that is affected by energy expenditure. Changes in lying behavior may be related to a state of chronic stress (Ladewig and Smidt, 1989). Reduced mobility and increased rest may be strategy of energy conservation in order to allow more energy to be spent on fighting the infection and to allow the full development of a fever, which may help the animal recover (Aubert, 1999).

Cook et al. (2007) video recorded lying behavior of 14 dairy cows over all seasons and discovered that mean lying time decreased from 10.9 to 7.9 hours/day from the coolest to the hottest session recorded because of heat stress ($P < 0.01$). Additionally, cows with greater locomotion scores (using a 1 to 4 scale where 1 represents non-lame and 4 represents severely lame) lied down more (2.9, 4.0, and 4.41 hours/day for locomotion scores 1, 2, and 3, respectively; $P < 0.01$ between 1 and 2; $P = 0.02$ between 1 and 3), indicating that pain may increase lying time.

Canadian researchers challenged 19 cows with an E. coli lipopolysaccharide and cited that baseline lying time (averaged from the two days before mastitis induction; 707.0 minutes/day) was higher than the day of induction (633.3 minutes/day; $P = 0.005$). Lying time increased on the two days after infusion (743.1 and 726.3 minutes/day for days one and two after infusion, respectively), but not significantly (Cyples et al., 2012). In a behavioral study of cows with naturally-occurring clinical mastitis, cows with clinical mastitis laid down more than control cows on the day after mastitis detection (707.5 versus 742.5 minutes/day, $P = 0.04$). However, no difference was observed in lying times of animals with mastitis that had been treated with antibiotics and control animals (Medrano-Galarza et al., 2012).

While physical discomfort may decrease dairy cow lying time, lying on hard surfaces may also exacerbate pain caused by mastitis, causing lying time to decrease during mastitis (Cyples et al., 2012). Chapinal et al. (2013) explained that lying down at the time when the most severe signs of local inflammation occur causes pain, forcing cows to stand for longer periods during mastitis. Total daily standing time was 20% longer for cows later diagnosed with clinical ketosis during the week before calving (14.3 ± 0.6 vs. 12.0 ± 0.7 h/d) and 35% longer on the day of calving (17.2 ± 0.9 vs. 12.7 ± 0.9 h/d) compared to those without ketosis, but no differences were observed postpartum. Cows later diagnosed with clinical ketosis also stood up fewer times (14.6 ± 1.9 vs. 20.9 ± 1.8 bouts/d) and stood for longer periods (71.3 min/bout vs. 35.8 min/bout) than cows without clinical ketosis on the day of calving (Itle et al., 2014). Cows with ketosis behave in a subordinate fashion (Itle et al., 2014), causing them to be less motivated to engage in behaviors that are energetically expensive like changing position from lying to standing (Susenbeth et al., 2004) or competing for feed (Goldhawk et al., 2009). Ketosis is a progressive disease associated with gradual changes in non-esterified fatty acids and blood glucose, starting in the prepartum period and progressing toward the more severe fatty liver disease (Bobe et al., 2004). Other researchers cited that postpartum activity was reduced among cows that were diagnosed with subclinical ketosis (502.20 ± 16.5 vs. 536.6 ± 6.2) (Liboreiro et al., 2015). Cows diagnosed with metritis had reduced postpartum activity (512.5 ± 11.5 vs. 539.2 ± 6.0 arbitrary unit) (Liboreiro et al., 2015).

Feeding time. Dry matter intake, rumination time and feeding time are important parameters for detecting illness. In order to increase milk production, energy requirements must be met. Researchers indicated that disturbances of fermentation and rumen activity can lead to subclinical and clinical diseases (Nocek, 1997, Maekawa et al., 2002). Consistently monitoring feeding behavior is a tool for tracking the health status of the whole herd or individual cows (Hansen et al., 2003). Edwards and Tozer (2004) explained that cows with ketosis had lower activity ($P < 0.01$) than healthy cows up to 5 DIM, but then actually became more active after 12 DIM. The difference in activity may have been due to sick cows having lower appetites, spending less time at the feed bunk, and spending more time lying down. During the week before, week after, and two weeks after calving, the dry matter intake (DMI) of cows with subclinical ketosis was 18, 26, and 20% lower that the DMI of cows without subclinical ketosis after calving ($P < 0.01$). Cows with subclinical ketosis also visited the feeder 18, 27, 28, and 16% fewer times during two weeks before, one week before, one week after, and two weeks after calving and spent less time at the feeder the same weeks (Goldhawk et al., 2009).

Cows with severe metritis consumed less feed than healthy cows beginning 2 weeks before calving and continued to consume less dry matter through three weeks post-partum. Cows with mild metritis ate less dry matter compared with healthy animals during the week before calving and throughout the 3-wk postpartum period. The odds of severe metritis increased by 2.87 for every 1 kg decrease in DMI during the week before calving. The odds of severe metritis increased by 1.72 for every 10-min decrease in feeding time during the week before calving. During the two weeks before calving, healthy cows displaced others from the feed bins 16.8 ± 1.74 times/d compared with severely metritic cows who only displaced others on average 12.2 ± 1.58 times/d ($P = 0.06$) (Huzzey et al., 2007). Urton et al. (2005) also explained that cows with acute metritis spent 24 minutes less at the feed bunk compared to those without acute metritis between 12 days pre-calving to 19 days post-calving ($P < 0.01$). In this study, the odds of a cow having metritis increased by 1.97 for every 10-minute decrease in average daily feeding time. Hansen et al. (2003) cited a linearly negative relationship between feed intake and plasma calcium level in cows with induced hypocalcaemia.

Rumination time. Rumination is defined as the regurgitation of fibrous ingesta from the rumen to the mouth, remastication, followed by swallowing and returning of the material to the rumen. Dairy cows normally ruminate for eight to nine hours a day when measured by visual observation. Researchers in a Vermont study fitted steers with a facemask that restricted all jaw movement for ten hours a day during the study period. When the facemask was removed, the steers were offered hay, but the animals instead chose to ruminate (Welch, 1982). A more recent study using rumination collars by Kaufman et al. (2016) cited rumination times of 7 and 8 hours for primiparous and multiparous cows, respectively.

Rumination is affected by diet, including feed digestibility, neutral detergent fiber intake, forage quality (Welch and Smith, 1970), and particle size (Welch, 1982). Rumination time decreases with acute stress (Herskin et al., 2004) and disease (Welch, 1982, Hansen et al., 2003). Researchers have estimated rumination based on direct visual observations, but systems now exist to automate this process (Schirmann et al., 2009). Automated rumination-monitoring system was validated by comparing values from a rumination logging device with those from a human observer for 51 two-hour observation periods on 27 Holstein cows. Rumination times from the electronic system were highly correlated with those from human observation ($R = 0.93$), indicating that the automated system accurately monitored rumination in dairy cows (Schirmann et al., 2009).

Kansas researchers studied nine Angus-Hereford cows and observed that high cortisol levels (above 22 ng/mL, the mean of the group) were highly correlated with less time spent ruminating ($r = -0.85$, P < 0.01). Cortisol is released when an animal is stressed, therefore an association between stress and decreased rumination may exist (Bristow and Holmes, 2007). However, decreases in rumination may not always occur around stress. A study examining behavioral changes related to increased stocking density reported that at 100% stocking density, 95.1% of rumination occurred within a stall, but as stocking density increased to 142%, only 87.3% of rumination occurred within a stall. However, overall rumination time did not decrease between any of the stocking densities (P > 0.05) (Krawczel et al., 2012).

Cows diagnosed with metritis had reduced postpartum daily rumination time (416 vs. 441 minutes/day) (Liboreiro et al., 2015). Induced hypocalcaemia resulted in reduced rumination time, possibly related to the anti-peristaltic esophageal movements during rumination (Hansen et al., 2003) or decreased ruminal contractions (Jorgensen et al., 1998) because Ca is required for muscle contractions (Hansen et al., 2003).

Kaufman et al. (2016) explained that cows with greater rumination time the week before calving was associated with decreased odds of ketosis. The odds of a cow getting ketosis and another health problem increased when rumination time decreased from 1 week before calving to one week after. Rumination time decreased in primiparous and multiparous cows from two weeks prepartum and began to increase from weeks 1 to 2 postpartum. The increase postpartum may represent changes in dry matter intake. Clément et al. (2014) explained that rumination was a small, but significant, contributor in dry matter prediction. However, rumination time within weeks and cows are variable, making it difficult to use rumination time to predict dry matter intake. Primiparous cows ruminated less than multiparous cows 3 and 4 weeks postpartum (Kaufman et al., 2016). Maekawa et al. (2002) visually observed rumination times and explained that primiparous cows ruminated 52 minutes per day less than multiparous in mid-lactation.

Milk yield and components. Milk yield began to decrease 6 d before clinical ketosis diagnosis and remained lower (P < 0.01) than that of healthy cows (cows without ketosis, displaced abomasums, or digestive disorders) until at least d 10 after diagnosis (Edwards and Tozer, 2004). Cornell researchers cited that milk loss started 4 weeks before and continued for at least 2 weeks after a clinical ketosis diagnosis. The daily milk loss was greatest within the first 2 weeks after diagnosis: 3, 4, 3, and 5 kg/d for parities 1, 2, 3, and ≥ 4, respectively. The overall production loss during lactation was between 126 and 535 kg per cow. Cows without clinical ketosis in parity 1 yielded 1 kg less milk/day and cows in parity 4 or greater yielded 2 kg less milk/day than cows with clinical ketosis in the same parity (Rajala-Schultz et al., 1999a). In another study, cows with clinical ketosis produced 141.1 kg more 305-d yield than cows without clinical ketosis, but production was 44.3 kg less over 17 d following diagnosis (Detilleux et al., 1994). However, Rowlands and Lucey (1986) cited a 7% decrease in peak milk yield but overall no difference in 305-d yield. In contrast, Dohoo and Martin (1984) explained that a case of clinical ketosis increased milk production by 2.5%. The authors contributed this beneficial effect to the initial treatment of cows with clinical ketosis with malt or propylene glycol. However, it is likely that the cows with ketosis were higher yielding and were able to continue milking more even after ketosis, which was also the case in (RajalaSchultz et al., 1999a).

Average daily milk production during the first 21 d after calving did not differ between cows with subclinical ketosis compared to those without (Goldhawk et al., 2009). Higher producing cows are at greater risk of ketosis, which comes with a temporary milk yield decrease, so if they do not develop ketosis their milk yield would be even greater (Detilleux et al., 1994, RajalaSchultz et al., 1999a). Milk yield began to decrease 6 d before clinical ketosis diagnosis and remained lower ($P < 0.01$) than that of healthy cows (cows without ketosis, displaced abomasums, or digestive disorders) until at least d 10 after diagnosis (Edwards and Tozer, 2004). Cornell researchers cited that milk loss started 4 weeks before and continued for at least 2 weeks after a clinical ketosis diagnosis. The daily milk loss was greatest within the first 2 weeks after diagnosis: 3, 4, 3, and 5 kg/d for parities 1, 2, 3, and ≥ 4, respectively. The overall production loss during lactation was between 126 and 535 kg per cow. Cows without clinical ketosis in parity 1 yielded 1 kg less milk/day and cows in parity 4 or greater yielded 2 kg less milk/day than cows with clinical ketosis in the same parity (Rajala-Schultz et al., 1999a). Detilleux et al. (1994) explained that cows with clinical ketosis produced 141.1 kg more 305-d yield than cows without clinical ketosis, but production was 44.3 kg less over 17 d following diagnosis. However, Rowlands and Lucey (1986) cited a 7% decrease in peak milk yield but overall no difference in 305-d yield. In contrast, (Dohoo and Martin, 1984) explained that a case of clinical ketosis increased milk production by 2.5%. The authors contributed this beneficial effect to the initial treatment of cows with clinical ketosis with malt or propylene glycol. However, it is likely that the cows with ketosis were higher yielding and were able to continue milking more even after ketosis, which was also the case in (Rajala-Schultz et al., 1999a).

Canadian researchers discovered that milk production was less in cows identified with severe or mild metritis during the first three weeks after calving. The decreased yield is likely a consequence of the decreased dry matter and water intake observed after calving in the cows with severe and mild metritis (Huzzey et al., 2007). Mahnani et al. (2015) explained that a case of metritis reduced 305-d milk yield by 129.8 ± 41.5 kg per cow per lactation. In contrast, Wittrock et al. (2011) cited no difference in milk yield between cows with metritis and those without.

Sensitivity/specificity. Reneau (1986) outlined the ideal clinical test as being able to establish the presence or absence of disease in every case screened without any false positives or false negatives. He also suggested that the ideal test would provide a correct diagnosis, data to aid in prognosis, an indication of subclinical disease, data that may indicate possible disease reoccurrence, and would also be able to monitor treatment effects. Correctly identified events are considered true positives (TP), non-alerted events are false negatives (FN), non-alerted non-events are true negatives (TN), and alerted non-events are false positives (FP) (Firk et al., 2002). Specificity is the probability that a negative sample is from a disease-negative cow. Sensitivity is the probability that a positive alert is a true indicator of a disease (Hamann and Zecconi, 1998, Sherlock et al., 2008, Hogeveen et al., 2010b). Because sensitivity and specificity are interdependent, thresholds should be set to optimize both (Hogeveen et al., 2010b). Specificity is equal to TN / (TN + FP) x 100. Sensitivity is determined by the following equation: TP / (TP + FN) x 100 (Sherlock et al., 2008, Hogeveen et al., 2010b). Accuracy, which can account for the prevalence of a disease whereas sensitivity and specificity cannot, can be determined by: [(TP + TN) / (TP + TN + FP + FN) X 100]. Accuracy depends on how strongly and closely the measured parameters are associated with the event, how accurately the technology measures the parameters, and how well the manufacturer algorithm processes the data to create useful alerts (Dolecheck et al., 2015).

Positive predictive value is the proportion of true positives against the apparent positives (Hamann and Zecconi, 1998). A true positive occurs when the event occurs with an alert from the automated detection system (Hogeveen et al., 2010b). Negative predictive value is the proportion of true negatives against the apparent negatives (Hamann and Zecconi, 1998). A true negative occurs when the event does not occur and an alert is not produced (Hogeveen et al., 2010b). False positives, or type I errors, can cause financial losses because healthy animals may be treated. Conversely, false negatives, or type II errors, may leave sick animals untreated causing animal welfare problems and decreased milk yield and health throughout the lactation (Burfeind et al., 2010). Therefore, although a 90% sensitivity may seem acceptable in a research setting, it would likely be inadequate when applied in a herd setting (Sherlock et al., 2008). Steeneveld et al. (2010) explained that a general complaint of producers using robotic milking systems was the “relatively large” amount of false alerts. Even the most sensitive and specific test still needs to be available and affordable (Reneau, 1986). To be a valuable commercial management tool, cow performance should be related to the potential improvement in management of subclinical disease (Nielen et al., 1995).

Sensitivity and specificity of a disease detection tool depend on the disease definition (Nielen et al., 1995) and time window (Mollenhorst et al., 2012) in which alerts can be given. Wider time windows will produce a higher sensitivity and specificity (Hogeveen et al., 2010b, Kamphuis et al., 2010), but they will also lose their practicality in a commercial setting (Kamphuis et al., 2010).

The results of a survey of 139 Dutch producers that owned an automated milking system revealed that farmers preferred a clinical mastitis detection system that produced few false alerts and provided alerts for severe cases with enough time to take effective treatment action. Producers preferred that time windows were set at a maximum of 24 hours before clinical symptoms appear. However, variation in responses to the survey varied greatly, suggesting that detection systems should be adaptable to match the conditions of each farm (Mollenhorst et al., 2012). Kamphuis et al. (2010) used an alert time window < 24 hours, but the authors were not confident that it was the correct window to use for other studies. The use of a decision tree and this narrow time window resulted in 40% sensitivity and 99% specificity. Rasmussen (2002) suggested that a clinical mastitis system should provide 80% sensitivity and 99% specificity and that time windows should be within 24 to 48 hours of a clinical mastitis event.

Sensitivity and specificity will be lower if a new test disagrees with the comparison to the gold standard. Disagreement between the gold standard and a new test is often interpreted as the test lacking capability. However, the test could be better at detecting negatives, causing true negatives to display as false negatives (Nielen et al., 1992). This problem is made even more complex by the circumstance that neither the new test nor the gold standard detection methods may be ideal (Vickers et al., 2010). A universally accepted gold standard does not exist, though. Another limitation of an automated disease detection method is that clinical infections are infrequent, causing statistical analyses to be “weak” (Mein and Rasmussen, 2008).

Conclusions

Dairy cow diseases, particularly during the transition period, are expensive and compromise cow well-being and milk production. Current disease detection methods rely on visual observation. However, early disease detection may allow producer intervention (e.g. antibiotic treatment), thus decreasing the negative economic and well-being implications of the disease. Precision dairy technologies, or technologies that reside in and on cows to monitor individual cow physiology, production, and behavior, may be able to predict and detect disease and alert producers to cows with changes in the indicators monitored.

Notes:

Notes: